



ENG450: Engineering Internship

# FMG: Wet Front End

Final Report

Student:

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Date:

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Version:

1.1

## Declaration:

All of the work contained in this document is the work of the author unless otherwise stated and referenced. This document in its entirety adheres to the plagiarism policy outlined by Murdoch University. I solemnly declare that to the best of my knowledge, no part of this report has been submitted here or elsewhere in a previous application for award of a degree. All sources of knowledge used have been duly acknowledged.

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## I Acknowledgements

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I would like to offer my sincerest gratitude to the staff at Murdoch University. The dedication of my lecturers has seen me emerge as a talented graduate with a vast array of instrumentation and control knowledge. In particular I would like to highlight the work of Dr. Linh Vu and Associate Professor Graeme Cole. Linh drives the fundamentals of physics and mathematics into all areas of the Instrumentation major and is an inspiration to me. Graeme is the master and commander of a unique course which involves connecting the electrical (computer) world with the physical world. If he passes on a fraction of his electrical knowledge I will benefit greatly. I believe the course I have undertaken will set me apart from other graduates and make me a highly valued member of society.

I would also like to offer thanks to the team at Motherwell Automation. This work environment was fantastic for developing engineering skills in my field of study. Special thanks go to Paul Jones for the supportive role as industry supervisor. Similarly thank you to the project team members Jason Tan, Mauricio Valdez, Sholeh Pirmorady, Daniel Newton, Ben Ratcliffe and Project Manager George Immink. I greatly appreciated the opportunity to work with such skilled engineers.

To my friends and colleagues at Murdoch University I offer thanks. The teams I have been a part of over the years have changed me for the better.

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## II Executive Summary

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During the final stages of a bachelor of engineering at Murdoch University students are required to undertake a thesis or internship. This is a final assessment that ensures the student can draw from their past material to produce a large project or experiment. This will in turn prepare the student for a work placement in the industry.

This report is a final document for an engineering internship at Motherwell Automation that started in semester two of 2012. The internship project titled FMG: Wet Front End involves the upgrade to an iron ore processing facility in the Pilbara region of north Western Australia. The upgrade was a project acquired by Motherwell which included the installation of several new section that required electrical and automation systems. For this upgrade a large section of work involved designing the SCADA or human machine interface that the future process engineers at FMG would use. This was the majority of work completed by the internship student and this report will indicate this.

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**VI Table of Symbols and Abbreviations**

Abbreviation/Symbol	Meaning
FMG	Fortescue Metal Group
I/O	Input/output
ICE	Instrumentation and Control Engineering
ICSE	Industrial Computer Systems Engineering
FAT	Factory Acceptance Test
SAT	Site Acceptance Test
PLC	Programmable Logic Controller
HMI	Human Machine Interface
SCADA	Supervisory Control And Data Acquisition
CCR	Central Control Room
VSD	Variable Speed Drive
PC	Personal Computer
PCS	Process Control System
P&ID	Piping and Instrument Diagram
DOL	Direct On Line
EGD	Ethernet Global Data
GE-IP	General Electric Intelligent Products
PAC	Programmable Automation Controller
CSV	Comma-separated values

# 1 Introduction

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## 1.1 DOCUMENT INTRODUCTION

This document provides an overview on the work done for Fortescue Metal Group (FMG) by Motherwell Automation as part of an engineering internship at Murdoch University. The project is named Wet Front End Expansion and refers to and upgrade of the processing facility at Cloudbreak mine site. A team of engineers was assembled to complete the automation for this upgrade. The student was positioned as part of this team.

The current facility is operational, and yet not optimised. The plant is to be altered in such a way that increases the quality of the ore. This means that new objects (pumps, control valves, motors, compressors and digital valves) are required to be installed and automated. Each of these objects may be part of an electrical control system and electrical monitoring coupled with a user friendly interface. This task is the main objective of this project and includes many aspects of the Industrial Computer Systems Engineering (ICSE) and Instrumentation and Control Engineering (ICE) majors.

During this project a range of hardware and software was used to create a solution for the project. This created an effective learning environment and exposed the student to a range of industrial applications in the chosen engineering majors.

## 1.2 BACKGROUND ON MOTHERWELL AUTOMATION

Motherwell Automation is an Australian company that was established over 20 years ago. This firm operates out of offices in Osborne Park. This company has had a strong history in information systems but recently have moved towards the following electrical engineering areas:

- Networking and communications
- Supervisory Control and Data Acquisition (SCADA)
- Process Control and Instrumentation
- General Automation

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The specialization of Motherwell involves, but is not limited to, PLC programming and implementation. These embedded systems offer complete automation solutions to industries such as mining and resources, mineral processing, water and waste water, oil and gas, power and utilities, marine, rail and road transport, bulk materials handling and communications.

Motherwell has an emerging relationship with Murdoch University since providing internships for a number of students. They understand the requirements of an engineering internship and cater to them to the best of their ability.

## 1.3 BACKGROUND ON FORTESCUE METAL GROUP

FMG is an Australian Iron Ore Mining Company that operates mines in Western Australia's Pilbara region. This company holds the largest tenements of any iron ore mining company in Western Australia. These holdings are made up of the Chichester Hub and the Soloman Hub and cover more than 87000 Km<sup>2</sup>. FMG's first operational mine is Cloudbreak which is located in the Chichester Hub.

### 1.3.1 Cloudbreak Mine

Cloudbreak has been running since October 2007 and produced 28 million tons in its first year of operation. The output of this mine site is around 40 million tons of iron ore per annum. To better handle the huge production of ore both an ore processing facility and a railway system to Herb Elliot Port was constructed. The assigned project involves the processing facility at this site, the location of which is shown in Figure 1.3.1.1.

Fig 1.3.1.1: Map of Cloudbreak mine site showing its location in Western Australia.



### 1.3.2 Iron Ore Processing

The aim of the ore processing plant at Cloudbreak is not to refine the ore into metal but rather to produce better quality ore. The higher quality the ore the more it can be sold for. This is a dry process that includes:

- Infeed – Starting section made up of conveyor belts and bins.

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- Screening – Determines the appropriate path for the size of ore that is screened.
- Crushing – To reduce the size of feed material to enable further processing.
- Desands – To aid in removing impurities from the ore. This is a complex process that involves adding and removing moisture from the ore. The finer parts (sands) are also removed from the ore during this section. Ancillaries to this section include a flocculant producer and a thickener.
- Stacking – Another machine drive function that sorts the ore into appropriate sizing sections for transport.

### ***1.3.3 Optimisation***

The previous ore process works well and is suitable for high volume processing. However this process is far from optimised. As mentioned before, it is a dry ore process and yet the Pilbara region of Western Australia has an extensive wet season which can drastically reduce the ore quality produced. Running the wet ore, caused by either the rain or existing ground water, through the current dry ore process also increases the wear on equipment. The FMG: Wet Front End project is a plan to change the current dry ore processing plant into a wet ore processing plant. This will ensure a higher quality of ore is not only produced but maintained year round.

## 2 Project Scope

### 2.1 PROJECT OUTLINE

Wet Front End project involves enhancing the Cloudbreak iron ore processing facility. A combined hardware and software solution is required to upgrade the existing process control system. Motherwell Automation has proposed a solution whereby two additional PLCs will be added to meet this requirement. Of these two, one will be placed in the desands section of the plant. The other will be used to handle the PCS of a completely new section of the plant, wet screening and scrubbing. Many code changes will be added to the existing eight PLCs in order to facilitate the changes made. The full requirement of the PLCs includes all control modes, interlocking of equipment, alarming and the appropriate networking for relevant data transference both inter-PLC and to the CCR.

#### 2.1.1 Scope of Work

The PCS has many levels of control so that the process engineers who run the facility can operate it optimally. This means that the services offered by Motherwell Automation must include, but not be limited to:

- Additional screens to the existing SCADA system to include all new I/O, graphics, objects, alarms, interlocks and control systems as indicated by the P&IDs.
- Configuration of hardware as required by the Ethernet protocol.
- Configuration of the new PLCs including I/O, calculations and function block based logic.
- All necessary PLC coding in ladder logic.
- Configuration changes to the existing PLCs to tie-in to the new sections.
- Testing of modified configurations.
- Testing of new configurations.
- Develop and maintain a server-orientated database.
- Prototype testing of all new equipment including Profibus.
- Integration of the new PCS.

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- Safety practices such as multi-level interlocking are to be designed and implementation must be maintained at all times.

All works must conform to the standards given in Appendix 9.1. To aid with this substantial task, the client provided all necessary documents. These include schedules, drawings, calculations, technical data, shipping and packaging details, inspection certification and manuals. These documents were in turn used to create an appropriate design.

## 2.2 IRON ORE PROCESSING PLANT

Upgrading the facility from a wet ore process to a dry ore process requires a large amount of planning and resources. Two major changes (the desands upgrade and the new scrubbing section) apply to the plant and hence associated PCS must be changed/installed. Each section uses a number of mechanical components that are controlled via a PCS. Each component will be mentioned in the project equipment section. Figure 2.2.1 below shows the iron ore process sections from beginning to end after the implementation of the upgrade. The two section of interest are highlighted purple.

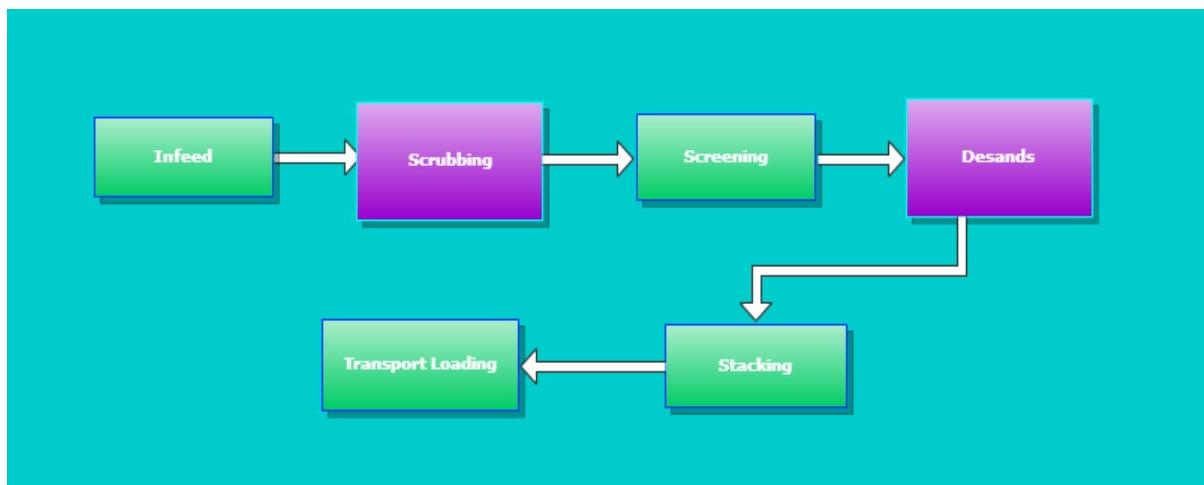


Fig 2.2.1: A flow diagram of the process facility. Upgraded targets shown in purple.

### 2.2.1 Desands

As part of engineering design, it is always encouraged to break down the problems. This exists during the unit ENG305: PLC systems where students are given a gantry crane to program, and a similar approach was made for FMG: Wet Front End. The desands section has already been operating as a three module system. Each module is the same and is required due to high

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volume. The modules also have a PLC assigned to manage that section of PCS. The pre-upgrade plant flow diagram is as follows. Figure 2.2.1.1 outlines a more in depth view of the process than the previous figure. A key difference is that it is how the operation stands before the upgrade commences. Effectively the scrubbing has been removed.

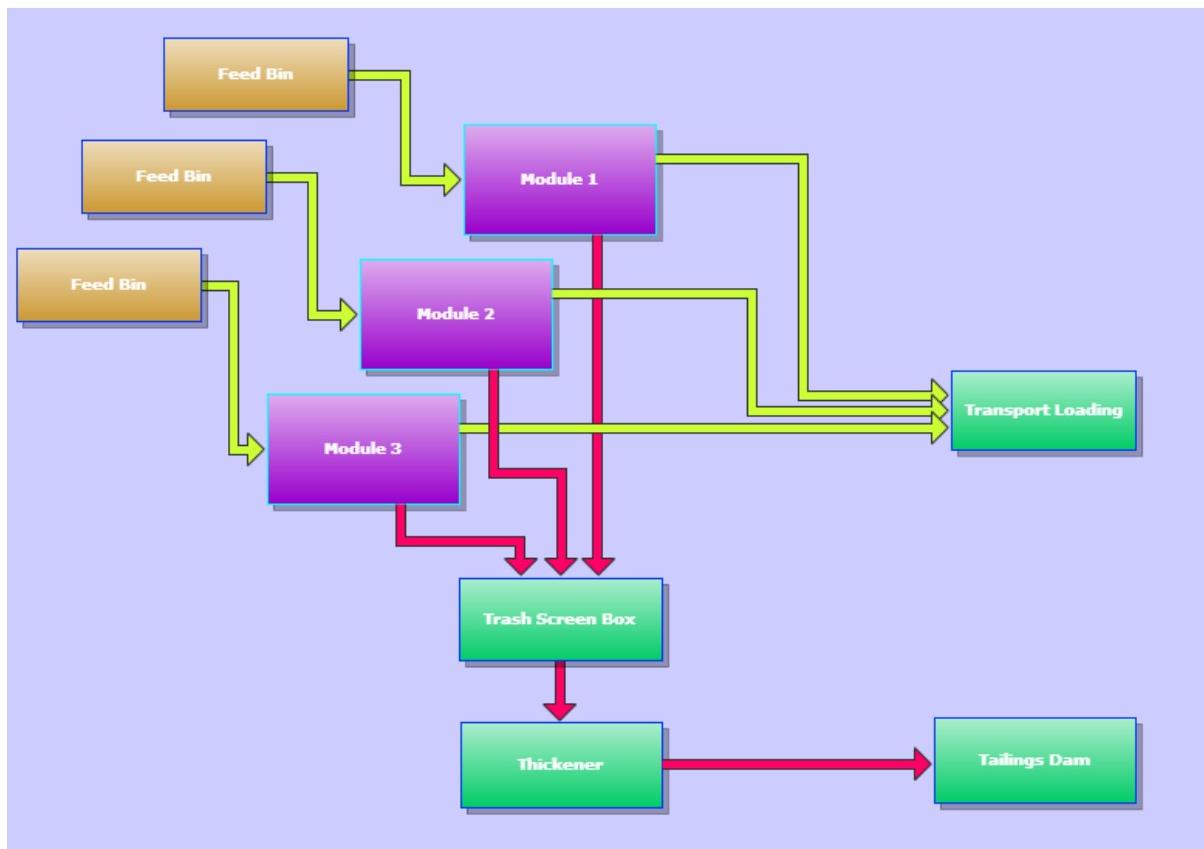


Fig 2.2.1.1: A flow diagram overview of the desands section shows the movement of the ore. Product ore is shown in yellow and the waste ore is displayed in red.

Each of the modules is identical before the upgrade. The process in this section of the plant is to separate the waste from the product. Graduate engineers will discover new process equipment in projects undertaken. Background research was completed to help gain an understanding of the client's needs. Each module contains:

- Feed Chute – regulates the ore feed upon entry to the module.
- Prep Screen – prevents oversized ore particles entering the classifiers.
- Pumps – These are either direct online (DOL) or VSD operated. Pumps assist in transporting the ore. Sometimes they are used in the control philosophy of the plant.

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- Sump Pumps – to prevent flooding in sections where the liquid level might build up in the plant. Simple control design has been added to these.
- Cyclone Clusters – used to dewater ore and separate fine waste before sending the ore to the classifier.
- Classifiers – specialist equipment that grades the ore to more accurately separate waste and bypass high quality ore straight to the stacking.
- Tanks – a variety of functions can be used with process tanks. Common purposes include mixing, heating, cooling and controlling density.
- Spirals concentrators – These are gravity-based devices that separate light density (sandy) materials from heavier density materials. As the ore travels down the spiral the denser material hugs the inside lane so to speak.

With all these items it is easy to see how each module performs the task of separating the product from the waste. Understanding the items helps to design an effective control system.

### ***2.2.2 Material Recovery***

The waste also goes through a process called thickening. Thickening has an ancillary section that produces flocculant. Flocculant is a liquid thickening agent. This is produced and then delivered to the thickener in addition to the waste material. The combined waste is then pumped to the tailings dam.

While the product ore is significantly more profitable, the resulting waste ore in the tailings dam can still turn a profit and will often be re-mined when the price of ore is sufficiently high.

## **2.3 PROCESS CONTROL EQUIPMENT**

The project scope has been outlined previously. This section highlights equipment that is used in the PCS. These objects were connected together to achieve the technical functionality required for the project. Each object will have a different amount of I/O which relates to its task within the larger process. A list of the equipment is given below.

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Object	Description	Digital I/O	Analogue I/O
RX3i	GE-IP PLC unit	N/A	N/A
Profibus PA	Field bus used for communications	Variable	Variable
DeviceNet	Field bus used for communications	Variable	Variable
Versamax Blocks	Distributed I/O units	Variable	Variable
VSD	ABB ACS800	256	32
DOL	CEP7 overload relay and DNY42R	16-128	N/A
Valves	Digital valves	16-64	N/A
Control Valves	Samson 3730	32	16
Analogues	Various sensors and transmitters	N/A	16

**Table 1**

Table 3 shows a list of the equipment used for the Wet Front End Upgrade. All of the objects are common to process control systems and many were given attention within the unit ENG345: SCADA Systems. This was however, not specific to the ones used in this project. This is no surprise since many of these objects exist from a very large number of vendors and suppliers.

### 2.3.1 RX3i PLC

The PACSystems RX3i is the most essential piece of hardware to the project. Some of these controllers are already established in the facility since the original install in 2007. The RX3i shown in Figure 2.3.1.1 carries a 1 GHz CPU with 64MB of memory and two serial ports. This is connected to a universal twelve slot base plate that allows other hot-swappable modules to be selected and fitted. Any of the modules fitted can be redundant including the CPU and/or power supply.

PACSystems RX3i



Fig 2.3.1.1: An RX3i rack with various attached modules. [24]

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### 2.3.1.1 I/O Modules

There are a number of ways to deliver the I/O to the CPU for an RX3i unit. This is referred to as a PAC. The difference between a PLC and a PAC is the functionality, networking options and expandability has been significantly increased in a PAC. The role of the PAC is changing and merging towards the combined function of a PLC, RTU and a DCS. [31] The I/O modules available to this unit are:

- Discrete I/O Module – Attaches to the base plate and is hot-swappable. Inputs commonly use switches, buttons, proximity sensors and BCD thumbwheels. Outputs used consist of relays, contactors, BCD displays and indicator LEDs.
- Analogue I/O Modules – Also hot-swappable and used with sensors and actuators.
- Distributed I/O – Communications modules provide options for distributed I/O. Choose from Ethernet, Profibus-DP, Genius Bus or DeviceNet.

### 2.3.1.2 Specialty Modules

Specific application requirements may make it necessary for these modules to be included. There are the millivolt and strain gauge I/O, the RTD I/O, the Thermocouple I/O, the Resistive I/O and the Power Transducer.

## 2.3.2 Profibus

Profibus is an established communications protocol for field bus applications. It is used to perform a cyclic data exchange through the master slave relationship. The PLC is the master in this case. Profibus PA and Profibus DP were both used for the project. The difference being that Profibus PA is considered safer (used exclusively in hazardous areas) and runs at a speed of 31.5 Kbit/s where as Profibus DP runs at a speed up to 12000 Kbit/s (depending on length). Both use the same communications protocol and can be connected in the same network using a DP to PA connector. [23]

## 2.3.3 DeviceNet

DeviceNet is an open field network that easily connects to field devices. This network has less wiring and as a result has less maintenance costs. The setback of DeviceNet is that it must be connected to DeviceNet devices. The performance of the network is determined by the length and thickness of the cable [15]. Figure 2.3.3.1 displays the capabilities of DeviceNet in accordance to its properties. It stands to reason that a longer cable should be run at a slower baud rate to accommodate errors over this distance since

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there will be a higher chance of errors from induction. The current will also influence this and is accounted for in the chart.

Cable type	Baud rate	Max. network length	Branch line length	Total branch line length	Current capacity
Thick cable	500 kbps	100 m	6 m max.	39 m	8 A
	250 kbps	250 m		78 m	
	125 kbps	500 m		156 m	
Thin cable	500 kbps	100 m	39 m	39 m	3 A
	250 kbps	100 m		78 m	
	125 kbps	100 m		156 m	
Flat cable	500 kbps	75 m	35 m	35 m	5 A
	250 kbps	150 m		48 m	
	125 kbps	265 m		135 m	

Fig 2.3.3.1: The DeviceNet performance chart [15].

### 2.3.4 Versamax Units

The Versamax units are the distributed I/O blocks used in this project. They are connected to the PLC via the Profibus DP and the Profibus module on the rack. Each module can accommodate for up to 32 points of I/O. The modules slide on to industrial DIN-rail. Versamax modules provide automatic addressing which eliminates the need for configuration. There is a large range of different I/O modules as well as Versamax PLCs and Power units. The large range allows the client to custom build the distributed I/O. Figure 2.3.4.1 gives a birds-eye view of a typical Versamax unit. The termination points exist on the lower part of the diagram while the connections to DeviceNet are hidden. Dim-rail is an industrial brass rail with holes in the centre so it can be screwed onto a flat panel. Dim-rail can be seen in Figure 2.3.4.1 extruding from either side of the Versamax module. This shows that it must be mounted on Dim-rail.

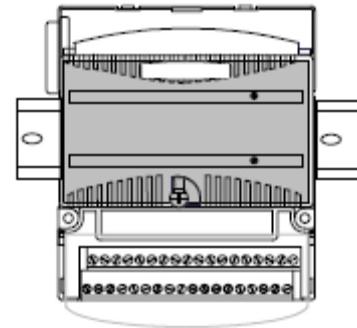


Fig 2.3.4.1: On the right is a Versamax I/O module with the terminals shown down the bottom. [25]

See Appendix 9.2 for the full list of I/O modules.

### 2.3.5 ABB ACS800 Drive

In this project ABB ACS800 variable speed drives were used to control conveyors and pumps. They are used to control the speed of these items to a set point. ABB drives are designed to handle the high power requirements of the process industry. Unlike most VSDs that use variable frequency, the

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ACS800 uses direct torque control (DTC). [12] DTC provides a high starting torque as well as accurate control of speed and torque. The exterior of the ACS800 is designed to withstand harsh environments by a combination of mechanical design and material selection. Two models of the ACS800 VSDs can be seen in Figure 2.3.5.1. They must be first mounted to the wall then wired to the motor (or other AC equipment) to suit specifications and requirements.



Fig 2.3.5.1: A pair of wall mounted ACS800s. [12]

### 2.3.6 CEP7 Overload Relay & DNY42R Starter

The CEP7 is a solid state microprocessor based overload relay designed for the protection of induction motors. [13] For the motors connected to these there is no variable speed. The motor will either be on and running at the specified rate or off. This kind of relay must be used in-between the field (AC) and computer control system (DC). The functions of the CEP7 are connected to the PLC which includes:

- Overload
- Phase loss (trip only)
- Stall (trip only)
- Jam
- Underload
- Current imbalance
- Number of starts
- Operating hours

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Fig 2.3.6.1:  
Wall mounted  
CEP7. The  
three pins at  
the top are  
connected to  
the field  
component.  
They are very  
large pins due  
to the very  
large currents  
that will be running through them. The underside is connected to the  
computer end (lower voltage and current) [13].



This device is coupled with the DNY42R which acts as a distributed starter for the DOL drive. The DNY42R connects the signal from the PLC over the DeviceNet to the CEP7 [14].

## 2.3.7 Samson 3730

The Samson 3730 is the control valve type used to control different systems in the project. It is an electro-pneumatic positioned meaning that it responds to a 4-20mA signal and moves accordingly using compressed air. This is the most common device used as the PID output. It is industrial sized to handle large flow rates and dense material such as the ore slurry in this project.

## 2.3.8 Analogue Sensors

Analogue sensors are the heart of a PCS. “For we cannot control what we cannot measure”. [6]

### 2.3.8.1 SS200 Density Gauge

The SS200 contains three major components to determine the density. These are the source housing (containing radiation source), the detector and the control unit with keypad and screen interface. The density is reported as specific gravity (ratio of slurry density to the density of water) and percentage of solids.

### 2.3.8.2 ABB Temperature Transmitter

The ABB temperature transmitter is an intrinsically safe sensor that uses RTD or thermocouple to sense temperature. It runs on the Profibus PA network.

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### 2.3.8.3 ABB Pressure Transmitter

The ABB pressure transmitter is rough pressure sensor with a base accuracy of  $\pm 0.15\%$  and a range of -0.3 to 60000 kPa. This hardware is designed to be robust to handle the extreme environments of the process industry.

### 2.3.8.4 Endress and Hauser Pressure Transmitter

The Cerabar S pressure transmitter can measure gases, steams/vapours and liquids. It can be used widely in the process engineering industry. It uses a ceramic diaphragm that deflects 0.025 mm proportionally to the pressure. There is a filling liquid between the diaphragm and a metal sensor creating a resistance bridge. The bridge output voltage can then be measured. [19]

### 2.3.8.5 Vibromac 107

A Vibromac 107 protects equipment by monitoring the vibration intensity. This can serve as a warning for potential hazards. The Vibromac is used on vibrating screens in the desands and scrubbing sections and can reduce downtime by creating well timed preventative maintenance.

The Vibromac 107 utilizes a microcontroller that measures lateral acceleration, exciter phase and oil temperature. The microcontroller stores the data for up to ten days and creates trending on this data as well as provides a frequency analysis. [17]

### 2.3.8.6 Sitrans DS3

The DS3 is a digital pressure transmitter Siemens instrument. It is highly accurate and user friendly. The Sitrans DS3 uses Profibus PA as a communications protocol. [21]

### 2.3.8.7 Sitrans PLU

The Sitrans Probe LU is an ultrasonic level transmitter. It uses time-of-flight based calculations to determine the level of up to 12m. It can also be used to calculate volume and/or flow rate. The sensor can be connected to a PCS via Profibus PA. [21]

### 2.3.8.8 Disocont

The Disocont is an embedded system used as a part of the conveyor belts. They provide the necessary scaling and output for mass travelling on a conveyor (into a bin). They are connected to a load cell or other weight measurement device then serve on the Profibus PA network. [22]

### 2.3.8.9 WIKA Temperature Transmitter

The T53 temperature transmitter is a dual functionality sensor. The user must define the specific functionality using the input settings on the

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transducer block. The transducer block has both an RTD and thermocouple. Profibus PA can be used to network this device.

### 2.3.8.10 Magflow 6000

The Magflow 6000 is a Siemens magnetic flowmeter sensor. It uses an electromagnet and calculates flow from the voltage induced. The requirement for this is that ions exist in the liquid. Iron ore slurry will have no problem generating this voltage. These sensors can use Profibus PA/DP or DeviceNet. [20]

## 2.4 DETAILED UPGRADE SPECIFICATIONS

The client has already designed the upgrades to the process facility. These have been mapped in a series of P&IDs. Any extra design requirements have been filled in on the design specifications handbook which was provided by FMG along with the P&IDs. Upon examination of these documents Motherwell Automation set out to design and implement the process control system.

Converting the written request of the client into a well designed PCS is a difficult task. The basic functionality must be achieved and the finer points must all be ironed out. P&IDs are technical diagrams that accurately express the location of sensors and actuators to be used in the PCS. P&IDs are used as the master source of information. This means that, where a written document is seen to conflict with the information on a P&ID, the written document will be overruled by the P&ID. The following PCS design was created using client documents in this manner.

### 2.4.1 Tag Names

Tag names are used throughout the industrial industry. They aid in designing large scale projects where the amount of objects used quickly exceeds the amount that most people can keep track of. They start with an abbreviation of letters and end with numbers. The letters indicate what type of object, while the numbers indicate placement and reference to other objects of that type.

### 2.4.2 Desands Area

The desands section has four existing PLC units. These must be altered to accommodate new equipment. A wet process will use more pumps instead of conveyors since the ore can now be considered liquid slurry. Major changes to this area include adding a module (module 4), adding a thickener

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(thickener 2), an extensive water supply system and changing the desands input to a cyclone feed tank. See Figure 2.4.1.4 for the full changes.

#### **2.4.2.1 PLC 4262**

This PLC contains the code that controls and monitors module 1. It will have the following objects added:

- ❖ Pump 232 – The dewatering screen pump (module 1)
- ❖ Pump 266 – The spirals conservation pump (module 1)

#### **2.4.2.2 PLC 4263**

This PLC contains the code that controls and monitors module 2. It will have the following objects added:

- ❖ Pump 234 – The dewatering screen pump (module 2)
- ❖ Pump 269 – The spirals conservation pump (module 2)

#### **2.4.2.3 PLC 4302**

This PLC contains the code that controls and monitors module 3. It will have the following objects added:

- ❖ Pump 236 – The dewatering screen pump (module 3)
- ❖ Pump 272 – The spirals conservation pump (module 3)

#### **2.4.2.4 PLC 4303**

This PLC is a new addition to the process facility. This unit will control module 4 and other new additions such as:

- ❖ AG261 – The agitator that mixes the cyclone feed tank.
- ❖ Pumps 285, 286, 287 and 288 – The pumps that are to become the new desands module feeds (one for each module). They are connected to the outflow of the cyclone feed tank.
- ❖ Digital Valves – Twenty valves that aid in controlling the pumps and flow of the slurry in module 4. They include eight gland water valves, four suction valves, four cyclone feed valves and four drain valves.
- ❖ Control Valves 6604, 6636-39 – The cyclone feed tank process water control valve. The classifier teeter water control valves.

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- ❖ Classifiers 237 and 238 – The classifiers for module 4.
- ❖ Pump 281 – The spiral feed pump.
- ❖ Pumps 282, 283 and 238 – The concentrate feed pump, spiral tails pump and dewatering screen underpan pump.
- ❖ Control Valves 6635, 6665, 6667 and 6668 – The spiral process water and dewatering screen process water control valves.
- ❖ Thickener 2 – An additional waste treatment thickener added to the process.
- ❖ Pumps 259, 260, 289, 290 and 296 – The pumps used in the thickener process.
- ❖ Digital Valves 6701, 6703, 6731-42, 6739 and 6740 – The valves used for the thickener.
- ❖ Control Valve 6706 – The flocculant dilution control valve.
- ❖ Pumps 291-295 – The gland water pumps and tailings disposal pumps responsible for transporting the post thickened waste to the tailings dam.
- ❖ Sump Pumps 243-247 and 280 – Thickener sump pumps. Tailings sump pump. Transfer line sump pumps. Process water area sump pump.
- ❖ Pumps 015-017 023, 256, 298, 299 and 101C – The pumps required for the new water services area.
- ❖ Digital Valves 6751-54 – Gland water valves for the new water services area.
- ❖ Control Valves 6751, 6754 and 6755 – Raw water control valves and the recycle water control valve.

In reference to Figure 2.2.1.1, Figure 2.4.1.4 is constructed to clarify the differences in the process facility after the upgrade. Some features remain the same and yet many areas are different and it is recommended to compare the following Figure to Figure 2.2.1.1 to gain a greater understanding of the upgrade overall.

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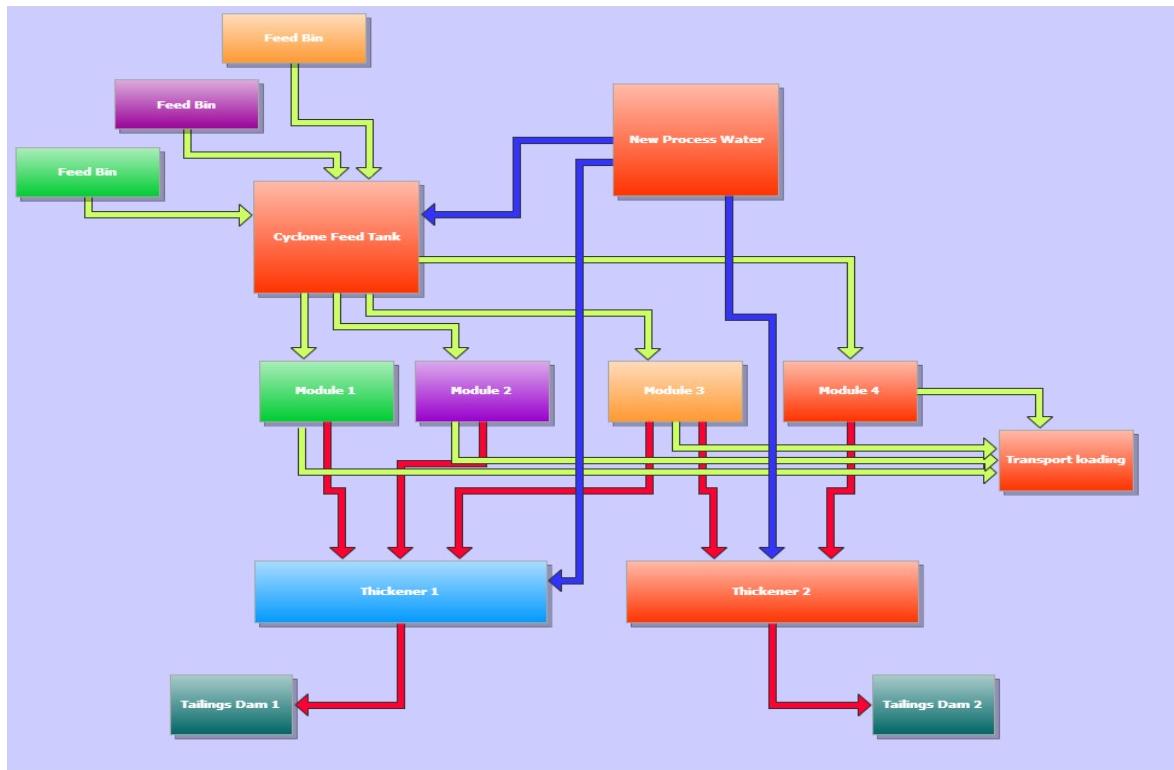


Fig 2.4.1.4: Desands overview as a wet process. The ore product is once again in light green. Process water is in blue and waste ore is in red.

Figure 2.4.1.4 is the resulting flow diagram of the expansion. It is colour coded as shown in Table 2 to show which PLC controls each section. There are some elements missing from this illustration as it should serve as a guide to the function of the desands process.

PLC	Colour
4262	Green
4263	Purple
4302	Light Orange
4303	Dark Orange

Table 2

The table reinforces that in figure 2.4.1.4 the colours of each process block shows which PLC effectively controls the electrical system in that block.

The overall process is more complex but has a higher volume and quality output. This serves to improve the overall efficiency and make this project a worthwhile investment.

### 2.4.3 Wet Scrubbing Area

Wet Scrubbing is a completely new section of the plant that fits in between the infeed and the screening. A new RX3i unit was used for the control

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system. This is PLC 5071. Many objects were included as part of this code. Some of these objects or machines were significantly more complex than previously worked on. These include:

#### 2.4.3.1 Scrubber 1

- ❖ DOL Pumps PU301-309 – The ancillary pumps for the scrubbing machine.
- ❖ DOL Heaters HE201-206 – The lube heaters for the gearbox and the main bearing.
- ❖ DOL Inch Drive GB214 – The drive in charge of breaking the locked charge as mentioned in control philosophy.
- ❖ DOL Screens SN214 and SN224 – To size the ore after it passes through the scrubber.
- ❖ VSD CV214, BF214, SB214 and PU224 – Scrubber 1 conveyor, scrubber 1 belt feeder, scrubber 1 drive and the fines screen underflow pump.
- ❖ Digital Valves SV6101, SV6149-54, FV6162-66 and SV6161 – All scrubber 1 support and ancillary valves.
- ❖ Control Valves FV6120-23 and FV6160 – To control the water added to each section to ensure a viscous flow.

#### 2.4.3.2 Scrubber 2

- ❖ DOL Pumps PU311-319 – The ancillary pumps for the scrubbing machine.
- ❖ DOL Heaters HE207-212 – The lube heaters for the gearbox and the main bearing.
- ❖ DOL Inch Drive GB215 – The drive in charge of breaking the locked charge as mentioned in control philosophy.
- ❖ DOL Screens SN215 and SN225 – To size the ore after it passes through the scrubber.
- ❖ VSD CV215, BF215, SB215 and PU225 – Scrubber 2 conveyor, scrubber 2 belt feeder, scrubber 2 drive and the fines screen underflow pump.
- ❖ Digital Valves SV6201, SV6249-54, FV6262-66 and SV6261 – All scrubber 2 support and ancillary valves.

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- ❖ Control Valves FV6220-23 and FV6260 – To control the water added to each section to ensure a viscous flow.

#### 2.4.3.3 Scrubber 3

- ❖ DOL Pumps PU321-329 – The ancillary pumps for the scrubbing machine.
- ❖ DOL Heaters HE213-218 – The lube heaters for the gearbox and the main bearing.
- ❖ DOL Inching Drive GB216 – The drive in charge of breaking the locked charge as mentioned in control philosophy.
- ❖ DOL Screens SN216 and SN226 – To size the ore after it passes through the scrubber.
- ❖ VSD CV216, BF216, SB216 and PU226 – Scrubber 3 conveyor, scrubber 3 belt feeder, scrubber 3 drive and the fines screen underflow pump.
- ❖ Digital Valves SV6301, SV6349-54, FV6362-66 and SV6361 – All scrubber 1 support and ancillary valves.
- ❖ Control Valves FV6320-23 and FV6360 – To control the water added to each section to ensure a viscous flow.

The naming conventions between scrubber objects are very similar. In most cases a single number change in the naming convention will show which scrubber that particular item belongs to. Other areas of this section also have objects such as:

- ❖ VSD CV123, CV125 and CV128 – The product transfer conveyors. Oversized, middlings and fines respectively.
- ❖ DOL SP202-205 – Sump pumps for the scrubbing area.
- ❖ DOL CL201-203 – The chillers that provided heat exchanges with cold water to control the gear grease temperature.

The scrubbing section is designed to take off the outer layer of the ore which it achieves with the large scrubbing machines. The outer layer is said to have the most impurity which improves the overall grade of the ore.

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Fig 2.4.2.3: An industrial scrubber similar to the one installed at Cloudbreak mine site. [29]

As the ore flows through the scrubber as slurry the scrubber is rotated by driving the gears on the side. The slurry will roll off the side towards the bottom of the scrubber and in doing so will scratch the ore along the rough surface inside the scrubber. Three scrubbers are installed to keep up with the large volume of ore produced at Cloudbreak.

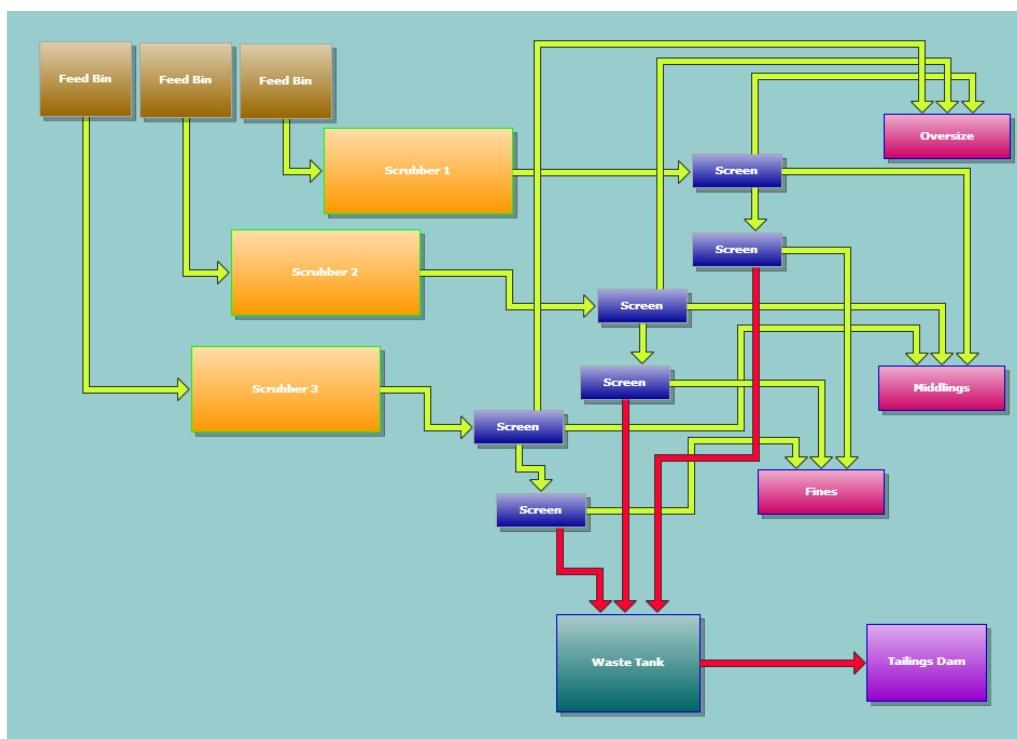


Fig 2.4.2.4: An overview of the Scrubbing section of the upgraded facility.

The system does not need to operate all sections at once since they are isolated. This helps to continue production when one of the scrubbers is due for maintenance. The ore travels from the feed bins to the scrubbers on conveyors and via pumps thereafter. The waste ore is shown in red.

## 3 Control Philosophy

A clear scope of the project FMG: Wet Front End has been established. Two main areas of the process facility are to be upgraded in accordance with the new process. Amongst this large scale project are specified control aspects that strongly relate to Instrumentation and Control Engineering. The major offered at Murdoch University supports these operations and is a large advantage to any student who works in automation.

### 3.1 PID LOOPS

The PID loops are the most common control algorithm used in this project. They are essential to the correct function of the plant and are included in the P&IDs and hence the SCADA. An analogue sensor will transmit some information to the PLC which then performs a calculation and alters a connected variable. The variable used (often a control valve) will then cause a change to the system so the sensor reads a desired value, or set point. Figure 3.1.1 gives an indication of the control philosophy from an interface. It indicates the path of data transferred which makes control loops possible rather than showing how they actually function.

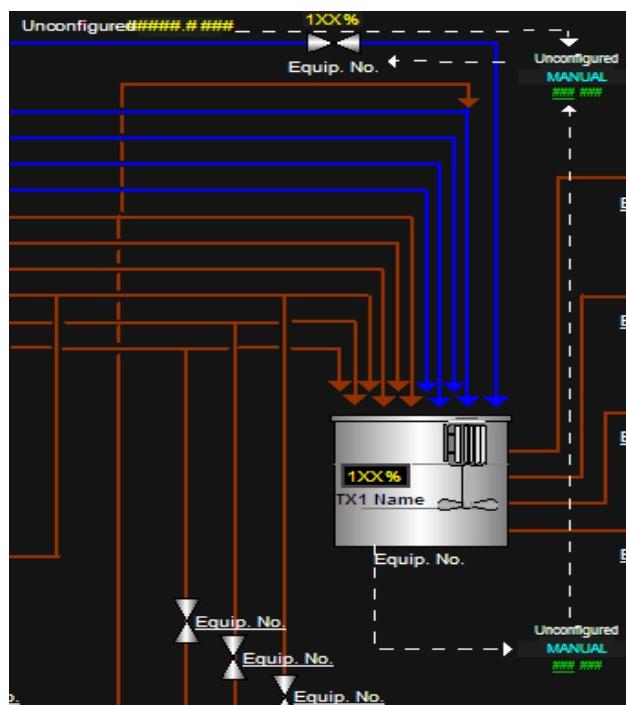


Fig 3.1.1: A simple PID loop as seen in the SCADA system.

Figure 3.1.1 shows a simple PID loop. The analogue sensor determines the flow rate of the water. If this rate is different from the desired rate (set point) then the valve is adjusted accordingly. The path of information is given by the dotted-white line. How much it is adjusted is dependent on the PID variables. These variables are set in the blue-green block in the SCADA. This is a standard control algorithm or 'loop'. In addition to general PID feedback control the project required more complex control loops such as the cascade control shown in Figure 3.1.2. Once again this is more of a data direction indication that can be used to help identify what is going on from a control theory perspective.

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Fig 3.1.2: A cascaded PID loop.



The figure to the right shows a difficult cascaded loop. This means that the process variable that is the level of the tank uses an inner loop involving the flow rate. The combined calculation of these determines how much the control valve is opened or closed. This will in turn change the flow of the water which also has the effect of changing the level of the tank. This idea is thoroughly explored in the unit ENG304: Advanced Process Systems.

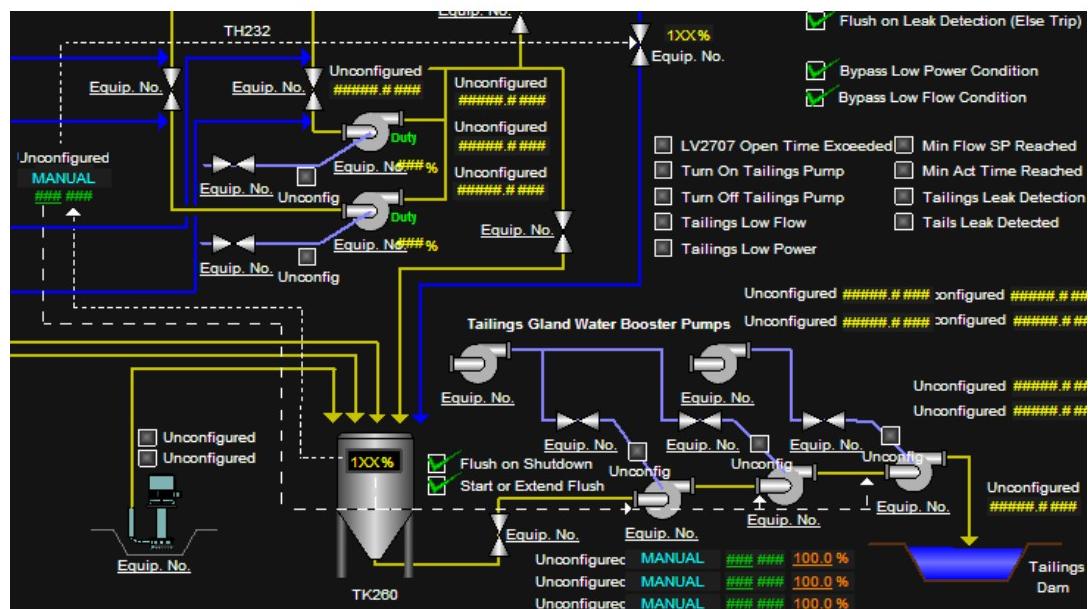


Fig 3.1.3: A more complex PID loop shown in the SCADA.

In this screen the dotted white lines shows the information transfer of the PID loop. It manipulates a control valve as well as the outflow pumps. This is due to the fact that not only the level of the tank must be controlled but also the density of the material in the outflow. Additional sensors must be to determine this and fed to the controller.

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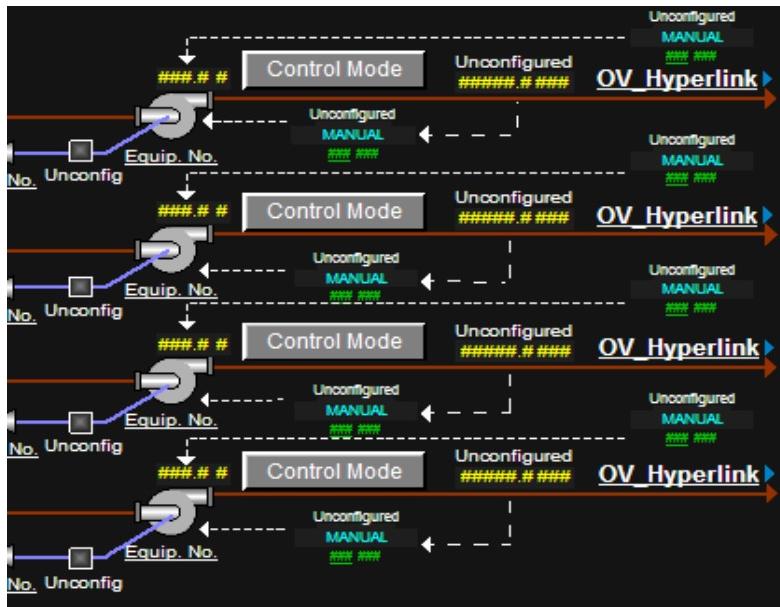


Fig 3.1.4: An alternating PID loop

In the above scenario the pump speed can be controlled by either a set point on the outflow rate or the density of the process material further down the system. In cases where the density cannot be measured, it is calculated using other sensors. The PID loops included in the upgrade are listed in the tables below.

No.	PID Name	PV (Sensor)	Modes	Manipulated Device/s
<b>Cyclone Feed</b>				
1	LIC6601	LIT6601	Man / Auto / CAS	FIC6604
2	FIC6604	FIT6604	Man / Auto	FV6604
3	FIC6603	FIT6603	Man / Auto	PU285
4	FIC6605	FIT6605	Man / Auto	PU286
5	FIC6607	FIT6607	Man / Auto	PU287
6	FIC6609	FIT6608	Man / Auto	PU288
7	PIC2529	PIT2529	Man / Auto	PU285
8	PIC2580	PIT2580	Man / Auto	PU286
9	PIC2765	PIT2765	Man / Auto	PU287
10	PIC6625	PIT6625	Man / Auto	PU288
<b>Classifier</b>				
11	FIC6636	FIT6636	Man / Auto	FV6636
12	FIC6637	FIT6637	Man / Auto	FV6637
13	FIC6638	FIT6638	Man / Auto	FV6638
14	FIC6639	FIT6639	Man / Auto	FV6639
<b>Spiral</b>				
15	LIC6635	LIT6635	Man / Auto	LV6635
16	LIC6666	LIT6666	Man / Auto	FV6665
17	FIC6662	FIC6662	Man / Auto	PU282
18	LIC6667	LIT6667	Man / Auto	FV6667
19	LIC6665	LIT6665	Man / Auto	FV6668
<b>Thickener</b>				
20	LIC6700	LIT6700	Man / Auto	PU289, PU290
21	LIC6711	LIT6711	Man / Auto / CAS	FIC6604

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22	DIC6731	DIT6731	Man / Auto	
23	PIC6711	PIT6711	Man / Auto	
24	FIC6732	FIT6732	Man / Auto	
25	FIC6706	FIT6706	Man / Auto	<b>FV6706</b>
26	FIC6707	FIT6707	Man / Auto	<b>PU296</b>
<b>Tailing Disposal</b>				
27	LIC6771	LIT6771	Man / Auto	<b>PU291,292,293,LV6771</b>
<b>Desands Water Services</b>				
28	FIC6755	FIT6755	Man / Auto	<b>FV6754</b>
29	LIC6751	LIT6751	Man / Auto	<b>LV6751</b>
30	PIC6752	PIT6752	Man / Auto	<b>PU256, 298, 299</b>
31	PIC6756	PIT6752	Man / Auto	<b>PU015, 016, 017, 023</b>
32	LIC6755	LIT6755	Man / Auto	<b>LV6755</b>

**Table 3 – List of PID loops for the desands upgrade.**

No.	PID Name	PV (Sensor)	Modes	Manipulated Device/s
<b>Scrubbing</b>				
33	FIC6120	FIT6120	Man/Auto	<b>FV6120</b>
34	FIC6121	FIT6121	Man/Auto	<b>FV6121</b>
35	FIC6122	FIT6122	Man/Auto	<b>FV6122</b>
36	FIC6123	FIT6123	Man/Auto	<b>FV6123</b>
37	FIC6160	FIT6160	Man/Auto	<b>FV6160</b>
38	FIC6220	FIT6220	Man/Auto	<b>FV6220</b>
39	FIC6221	FIT6221	Man/Auto	<b>FV6221</b>
40	FIC6222	FIT6222	Man/Auto	<b>FV6222</b>
41	FIC6223	FIT6223	Man/Auto	<b>FV6223</b>
42	FIC6260	FIT6260	Man/Auto	<b>FV6260</b>
43	FIC6320	FIT6320	Man/Auto	<b>FV6320</b>
44	FIC6321	FIT6321	Man/Auto	<b>FV6321</b>
45	FIC6322	FIT6322	Man/Auto	<b>FV6322</b>
46	FIC6323	FIT6323	Man/Auto	<b>FV6323</b>
47	FIC6360	FIT6360	Man/Auto	<b>FV6360</b>
48	LIC6161	LIT6161	Auto	<b>SIC6161</b>
49	LIC6261	LIT6261	Auto	<b>SIC6261</b>
50	LIC6361	LIT6361	Auto	<b>SIC6361</b>
51	PIC6001	PIT6001	Man/Auto	<b>SIC6001A, SIC6001B</b>
52	WIC6110	WIT6110	Auto	<b>SIC6100</b>
53	WIC6210	WIT6210	Auto	<b>SIC6200</b>
54	WIC6310	WIT6310	Auto	<b>SIC6300</b>
55	TIC6148	TT6148	Auto	<b>TCV6148</b>
56	<b>TIC6152</b>	<b>TT6152</b>	<b>Auto</b>	<b>TCV6152</b>

**Table 4 List of PID loops for the wet scrubbing upgrade.**

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The above tables list all the PID loops that are including in the project. Table 5 covers the desands section while table 6 is a list of the PIDs in the scrubbing section. The type of sensor (or transmitter) used can be seen by the first letter in that objects technical name. For example, FIT6120 refers to a flow meter. LIT6601 however, refers to a level transmitter. The same is true for pressure transmitters, weight transmitters, density transmitters and temperature transmitters.

When it comes to the output of the PID the target will commonly be a pump (PU) or valve (FV, LV or TCV). In the case where the output target is another PID then this is the result of cascading.

## 3.2 DEVICE INTERLOCKING

Not all analogue sensors are used in the PID loops. In most cases the sensors are use to safeguard the correct operating range for that particular system. Any analogue value that goes outside its normal range should trigger an event that will return it to a normal range. This is the theory behind interlocking. A good example of this is when a water tank is almost full the inlet valve can be turned off to prevent any further water from entering the tank. This example requires that the tank level be measured and the digital valve is electrically controlled (Off/On). The code for this is written in the PLCs using ladder logic.

### 3.2.1 Permissives, Inhibits, Process, Protection or Safety

Different types of interlocks exist in the project. The key differences are the actions taken when they are triggered. The name of each interlock is a clue to the action taken. The following interlock classifications exist in FMG: Wet Front End:

#### 3.2.1.1 Permissive Interlocks

Permissive interlocks are light guards against any failure in the system. They are designed to alert the process engineers of any areas of significance so appropriate action may be taken. Permissive interlock when triggered will result in an alarm yet the system is “permitted” to continue.

#### 3.2.1.2 Inhibit Interlocks

The inhibit interlock is similar to the permissive, however a stronger ramification is imposed. When a system object is already running and an inhibit interlock is triggered the object will be allowed to continue and an alarm is activated. If, however, the object has not yet started, it cannot be

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started if an inhibit interlock is triggered. In this way the object is said to be “inhibited” from starting.

### 3.2.1.3 Process Interlocks

Process Interlocks are hard stops to prevent any damage to the process system. They focus on how the process operates and uses information from the past area and the future area of the process to stop an object. When triggered, a process interlock will stop an object from running and prevent it from starting. Alarms will also be activated on the SCADA.

### 3.2.1.4 Protection Interlocks

Protection interlocks lie on the higher end of the anti-failing system. Any running object with a protection interlock triggered will be stopped and alarms shown in the SCADA. The object will also not be able to be started until the issue is resolved. These interlocks are in place to “protect” the system objects.

### 3.2.1.5 Safety Interlocks

The final level of interlocking is the safety interlock. Safety interlocks perform the same function as a protection interlock but over a number of objects that surround where the interlock was triggered in the system. A safety interlock such as the emergency stop push button creates a “safer” environment for anyone working on the process level.

## 3.2.2 General

A number of interlocks are applied to each object (generally) so they can be systematically safeguarded from failures. These are the interlocks that involve a common feature of all objects such as the communications. They include:

- Profibus Master Communications Unhealthy – inhibit interlock, given to every device on the Profibus DP/PA network.
- DeviceNet Master Communications Unhealthy – inhibit interlock, active on all DOLs.
- Group Crash Stop – If objects in the same group all crash simultaneously this will cause all the objects to be interlocked. Inhibit interlock, active on all devices excluding some valves.
- Drive Main Isolator Unhealthy – protection interlock, each drive, either DOL or VSD, will have this interlock. The isolator is triggered which will naturally prevent power from entering the drive.

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- Drive Main Contactor Unhealthy – protection interlock, the contactors used are equipped with fault sensors that will be passed on to the PLC creating this interlock.
- VSD Device Status Unhealthy – protection interlock, all VSDs are equipped with a microcontroller and can determine an error within its function.
- VSD Communication Unhealthy – protection interlock, this represents the Profibus PA failing to communicate to a VSD.
- Drive Speed Fault – protection interlock, VSD does not achieve the set point speed (within a set time) and reports this to the PLC.
- Versamax Communications Unhealthy – protection interlock, the PLC fails to communicate with a Versamax module.
- Emergency Shutdown Relay – safety interlock, the emergency shutdown has been activated in an extreme case emergency cause all object to stop. Every object has this interlock.
- Emergency Stop Push Button – safety interlock, located at various positions around the facility. Push buttons can be used in an emergency and shutdown an array of surrounding objects.

This covers the common interlocks that are included in this PCS. There are, however, vastly more than this. See Desands FAT Procedure Manual and Wet Scrubbing FAT Procedure Manual for the remaining Interlocks [8]. These others relate to either the process around an object, preventing a failure in the system or the object itself going outside a safe area of operation. In some cases analogue sensors are used to determine whether a safe operating condition is met.

### 3.3 SPECIAL CASES

Interlocking along with PID control loops make up the largest section of the control systems in FMG: Wet Front End project. The client has requested that more specific functions of the PCS must exist. This is the special function control of the scrubber machines. [5] These extra control features protect the scrubber machines since they hold a significant portion of the project cost. The scrubber is a large industrial machine that needs to have its parts frequently coated with lube to prevent any downtime. The ancillary system surrounding the scrubber is quite extensive and serves this purpose. Each system must be actively running while the scrubber is operational.

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### 3.3.1.1 Gearbox and Pinion Lubrication System

This system consists of two lube oil heaters and a pair of lube oil pumps for each gearbox and pinion. The function of the heaters must be to keep the lube oil temperature above the low point of 44 deg C and below the high point of 50 deg C. It performs this operation by turning on when the low set point is reached and turning off when the high set point is reached. This is called relay heater control [5].

The next required function for this section is called duty standby control [5]. This means that one of the pumps will be the main pump (duty pump) to use and the other pump will be a backup that turns on only when the primary pump has failed. If the secondary pump has also failed then it will switch over to the primary pump provided the issue has been resolved. The primary pump can be chosen.

### 3.3.1.2 Main Bearing Lube System

This area involves two lube conditioning pumps, three bearing lube main pumps, four lube oil heaters and a pair of accumulator release solenoid valves. This system will also contain a relay heater control for the same set points as the previous section as well as duty standby control for the first three pumps and the last two pumps. In addition to this the system will also contain accumulator valve control. This opens the valve every hour. If the flow rate out of the valve is less than a high set point then not enough oil has accumulated and a permissive interlock is triggered. If the flow rate is greater than this set point then the permissive interlock is reset.

### 3.3.1.3 Ring Gear Grease Spray System

The ring gear is a circular gearing that winds around the diameter of the scrubber. This gearing, which is connected to a pinion and coupled with a gearbox, gives the scrubber its rotary motion. Periodically three solenoid valves and a metering switch will release a metered amount of grease onto the ring gear. This operation, when run correctly, should operate as follows:

1. Two inner solenoid valves are energized.
2. The spray door solenoid valve is energized.
3. Six successive sprays are metered onto the ring gear.

During this operation certain conditions must be met. The third valve must open no more than 10 seconds after the first two. The pressure of the spray is measured and must remain above a certain point for all six sprays. If these conditions are not met then the grease cycle fail count increases by one. If the grease cycle fail count is equal or greater than five then a protection interlock is triggered on the scrubber.

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### 3.3.1.4 Bearing Oil Seal System

The bearing oil seal system regularly releases a metered amount of oil onto the main bearing seal located in the pinion. The function is controlled by two metering switches and a solenoid valve. An oil seal is considered successful when seven counts of each metering switch have been activated. If the oil seals has not completed after two minutes of operation the oil seal fail count is increased by one. When the oil seal fail count is more than five a protection interlock is triggered on the scrubber.

### 3.3.1.5 Locked Charge Protection

A locked charge is a result of ore slurry having rested for a period on the bottom of the scrubber and getting stuck to that area on the scrubber. In normal operation as the scrubber turns the slurry flows through and constantly rolls down the curve side of the scrubber. When a locked charge is present, the normal operation is prevented due to the fact the ore does not roll down the side and scratch the outer shell. Instead the ore may fall as a huge lump at one time and cause catastrophic damage to the machine. For this reason it is very important to prevent a locked charge.

Detecting a locked charge is the first stage of preventing one. This can be done one of three ways. The scrubber is fitted with a position sensor and two limit switches on the outer rim. Upon start-up the scrubber will pass two limit switches that are 70 degrees apart. It will then be stopped and the position will be recorded at that point. If the scrubber settles at a point greater than 10 degrees away from the original point (which should happen if something heavy is stuck on one side) then it will be said to have a locked charge. It will also be considered to have a locked charge when the position is less than 10 degrees but the scrubber fails to start within ten minutes of that measurement. Lastly the scrubber is assumed to have a locked charge if it has been resting with slurry for longer than thirty minutes. The locked charge triggers a protection interlock.

When a locked charge is detected it must be broken in order to resume operation. The scrubber has been fitted with an inching drive for this reason. The main drive will be rested and the inching drive will be activated in the case of a locked charge. When the scrubber is inched forward, the ore material is shaken apart preventing it from clumping. The scrubber will be inched forward for a fifteen minute interval. The timer values and interlock are then reset and the scrubber will assume the locked charge is broken. If the charge is not broken it should be detected again on the normal start-up.

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## 4 PLC System

The PLCs used in this PCS are the RX3i. This is a newer module GE controller that should be capable to handle the tasks we require. Programming for the project was specified to be written using ladder logic. The structure, however, was specific and unlike that taught in ENG305: PLC Systems. This is largely due to the differences between the Siemens and GE software. Experience with ladder logic aided the student contribution to this section of the project.

### 4.1 PLC SOFTWARE

The software used to program the PLCs is Proficy Machine Edition. This is GE-IP (Intelligent Products) software that allows the user to create powerful control and automation applications. The function most used in this project is the logic developer – PLC. The package comes with more than just a logic developer, however the building of a HMI was not required by the machine edition software as another software package was used for this. When opening the machine edition software the various section of the screen have different windows to allow the user access to all necessary information.

This can be seen below in figure 4.1.1.

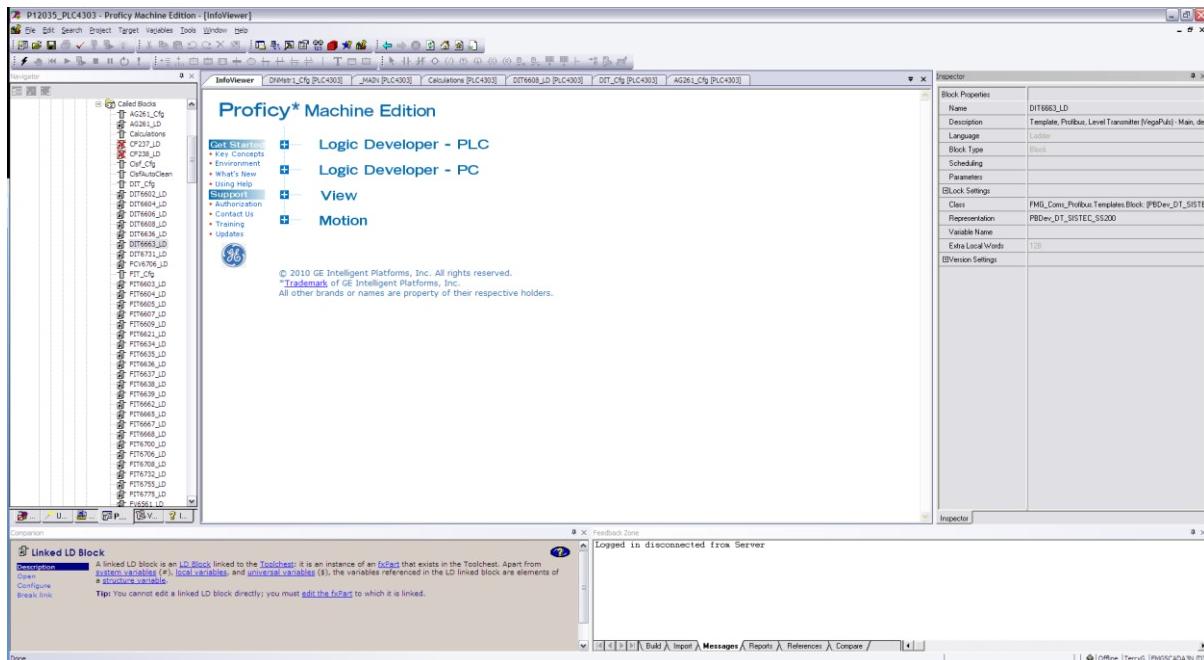


Fig 4.1.1: An overview of the main software screen

The main screen has a number of panels that the user must be familiar with in order to program. These include:

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- Reference Navigator – on the left can choose the display in the centre panel.
- Tool bars – across the top are useful to create ladder logic.
- Companion – is the bottom left panel and shows useful information about the currently selected item.
- Feedback Zone – on the bottom right gives information regarding ladder code, errors, server information, etc.
- Inspector – shown on the left in grey gives detailed system and configuration information.

Overall the package was easy to use and had some valuable features. This includes the toolbox feature. The toolbox is a server set up for storing function blocks that have been created either by GE-IP or Motherwell's in-house team. This means that anyone that can access the server can import the most up to date blocks to the project they are working on.

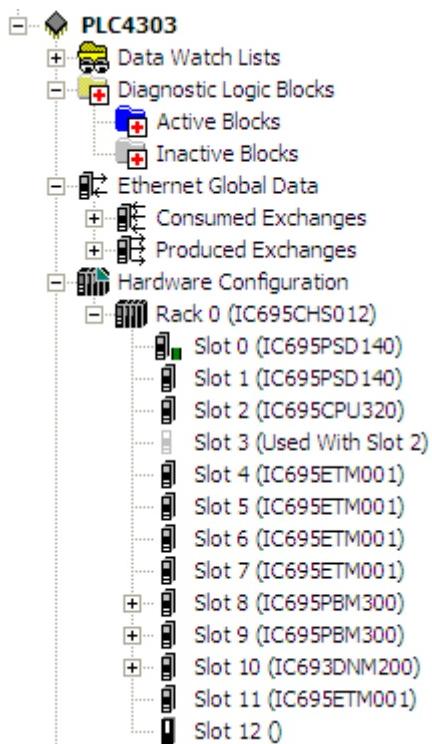
#### 4.1.1 Training

Motherwell Automation has a training division that supplies external companies with the basic introduction on GE-IP software and hardware. In the opening weeks of the internship specific training on this software was supplied to the intern. This training includes configuring and connecting to a PLC. Most areas of PLC functions were covered in the course ENG305: PLC Systems but other functions like Ethernet Global Data (EGD) and toolbox were new to the intern. Ethernet global data is a function of the PLC to communicate with other PLCs that share a physical connection through an Ethernet protocol cable. This made the training a worthwhile experience.

## 4.2 PLC CONFIGURATION

Configuring the PLC is a task that requires knowledge of all items on the rack. A rack is a twelve slot backplane that has interchangeable PLC modules. The basic PLC requires that there is a power supply and a CPU module. Since most of the I/O was received through a Versamax unit the racks each contains at least three communication modules. The following screenshot encapsulates the reference navigator when it is open to show the hardware configuration.

Fig 4.2.1: The hardware configuration as shown in PLC 4303. This PLC has a power supply, redundant power supply, CPU module, 4 Ethernet modules, 2 Profibus modules, DeviceNet module and an Ethernet module in slots 0 through 11 respectively.



This PLC shares many connections with other PLCs through the Ethernet global data (EGD) exchange. This uses an Ethernet protocol that requires each PLC to be assigned an IP address. Extra communications modules are included as redundancies.

## 4.3 LADDER LOGIC

Ladder Logic is a graphical programming style that is simple. It was designed for electricians and is based on the idea of activating a coil at the end of a wire (the way a simple circuit operates). The left side of the program is always active and coils are placed on the right with switching conditions in-between. Conditions are set between the active side and the coil. When the conditions are met the coil (which can be a system output) is activated.

Figure 4.3.1 was included to give a feel of the ladder logic and how it was written in the project. There are significantly large amounts of ladder logic in the project and some parts such as that shown in Figure 4.3.1 are simple and some are much more complex. The functions used in this figure are common the Machine Edition software and perform a relatively simple tasks.

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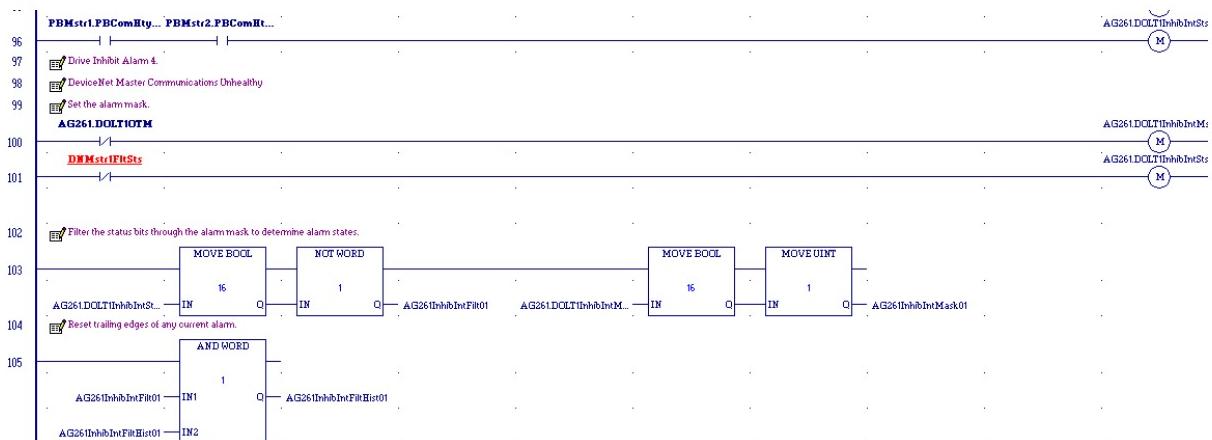


Fig 4.3.1: Some ladder logic code as used in the project.

In addition to activating a Boolean output (coil), blocks can be used for manipulations such as moving words of information and performing mathematics. Code should be commented wherever possible. This allows the programmer to remember the function of the code or another programmer to understand the code. The comments can be seen in purple in Figure 4.2.1.

Machine edition also offers a number of other programming languages such as script (GE-IP script or VBA), a state machine base language or standard logic text. None of these were used due to the specifications given by the client.

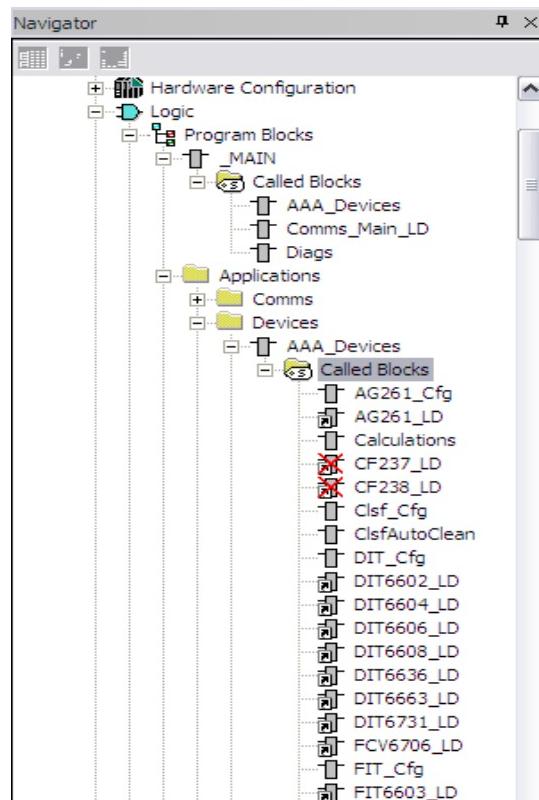
### 4.3.1 Ladder Logic Structure

The ladder logic for the project is function block orientated. Every scan that the PLC performs only reads the code written in main. However there is no ladder logic in main, only the three main function block. Comms\_Main\_LD, AAA\_Devices and Diags make up the key features of this PLCs role in the system. These function blocks also only contain other function blocks within them. In this way the project can be broken down in to individual devices, communications and diagnostics so it is much easier to navigate and debug should problems arise. The following figure (Figure 4.3.1.1) is a screenshot of the reference navigator again. Only this time it is highlighting the function blocks associated with the project.

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Fig 4.3.1.1: The ladder logic structure using function blocks. Main calls AAA\_Devices which calls all the devices blocks individually.

Another advantage from this type of block base orientation is that the code of one motor will be very similar to the code of another motor. Where this is the case the function block, and therefore the ladder logic, can be duplicated and I/O changed. This means that for all similar objects a comprehensive amount of time can be saved.



## 4.4 TESTING

Factory Acceptance Testing (FAT) began on the 20<sup>th</sup> of July and was completed on the 4<sup>th</sup> of September. This is code-only testing that ensures both the PLC code and SCADA run as expected before sending it to site. Given that each object has at least two function blocks of ladder logic and two screens in Cimplicity, the time for this task was significant and went well beyond the projected time (as discussed in the progress report).

A document must be created that can be “ticked” off as the test is completed. Both the client and Motherwell must retain a completed copy. Test templates have already been created in previous projects that explain how to test the objects in this project. The objects must then be listed according to this template and filled in. Objects are also divided into first section of the plant and then class.

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The screenshot shows a 'Document Map' window on the left and a detailed view on the right.

**Document Map:**

- PID
  - 5 Device Tests
    - 5.1 Scrubber 1 [SB214]
      - 5.1.1 DOL [PU301-PU309, HE201-HE206]
      - 5.1.2 VSD [CV214, BF214, SB214, PU224]
      - On-Off Valve [SV6101 SV6149-SV6154, FV6101 FV6152]
      - 5.1.4 Control Valve [TCV6148, TCV6152]
        - 5.1.4.1 Interface Checks
        - 5.1.4.2 Code Checks
        - 5.1.4.3 Control
        - 5.1.4.4 Auto Control
      - 5.1.5 Analogues and PIDs
    - 5.2 Scrubber 2 [SB215]
      - 5.2.1 DOL [PU311-PU319, HE207-HE212]
        - 5.2.1.1 Interface Checks
        - 5.2.1.2 Code Checks
        - 5.2.1.3 Mode Selection
        - 5.2.1.4 Permissives
        - 5.2.1.5 Warnings
        - 5.2.1.6 Inhibit Interlocks (InhibInt)
        - 5.2.1.7 Process Interlocks (ProcInt)
        - 5.2.1.8 Protection Interlocks (ProtInt)
        - 5.2.1.9 Safety Interlocks (Safint)
        - 5.2.1.10 Drive Control
        - 5.2.1.11 Run Hours
        - 5.2.1.12 Speed Setpoint
      - 5.2.1 VSD [CV215, BF215, SB215, PU225]
        - 5.2.1.1 Interface Checks
        - 5.2.1.2 Code Checks
        - 5.2.1.3 Mode Selection
        - 5.2.1.4 Permissives (PermInt)
        - 5.2.1.5 Warnings (Warn)
        - 5.2.1.6 Inhibit Interlocks (InhibInt)

**5.1.1 Interface Checks**

Item	Tag	Description
1.	PU301OL	Gearbox Lubri
2.	PU301RLY	Gearbox Lubri
3.	PU302OL	Gearbox Lubri
4.	PU302RLY	Gearbox Lubri
5.	PU303OL	Pinion Bearin
6.	PU303RLY	Pinion Bearin
7.	PU304OL	Pinion Bearin
8.	PU304RLY	Pinion Bearin

Test Engineer:

P12035E11002 Version 0.05

Fig 4.4.1: A FAT document map

The Scrubber 1 DOLs are tested first, followed by the Scrubber 1 VSDs and so on. This systematic approach safeguards that all the objects will be tested. The various checks performed in a FAT test can also be seen. These include:

- **Interface Checks** – The configuration of the object on the PLC, BUS, and physical address is checked. Used for DOL, VSD and Control Valves.
- **Code Check** – The code blocks in the PLC and the cimplicity screens are checked to see if they exist. Used for all objects.
- **Mode Selection** – The modes will be changed in every possible dynamic and tested to guarantee it is in the selected mode.
- **Interlocks** – The interlocks will be forced on then cleared one-by-one and the appropriate outcome is tested. For example a safety interlock should disable the motor when active. For a permissive however the motor is allowed to start but an alarm is shown. SCADA should also show the corresponding change on the interlock screen. Used for all objects.
- **Drive Controls** – The drives are tested again while triggering interlocks.

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- Auto Control – Tests the analogue value written as an output voltage.  
Used for control valves.

Other tests incorporate the sequences such as start-up/shutdown of the plant sections and special case control. This testing was designed and written by senior engineer Jason Tan. It shows great insight into how this system will operate and the relationship between objects (like a VSD pump and a drain valve).

#### ***4.4.1 Client test teams***

For the FAT testing FMG sent some test engineers to check the code alongside the Motherwell engineers. The testing was done in pairs with one engineer from each company. This team testing certifies that testing will be more accurate since someone who writes the logic may be unable to see its flaws. Many objects need to be tested so three teams were testing simultaneously. Each team was also given a SCADA support member to quickly debug any differences in the Cimplicity and to aid in client satisfaction.

## 5 SCADA System

System automation is a very modern approach to solving an industrial process. The human element however, cannot be omitted in such a complex array of subsystems. SCADA allows process engineers to stay involved in the process even though it is automated. This allows them to fine tune the process for maximum productivity. A SCADA system was required as part of the work scope for the project [7]. This system was set up on the existing software for the facility, Cimplicity 7.5.

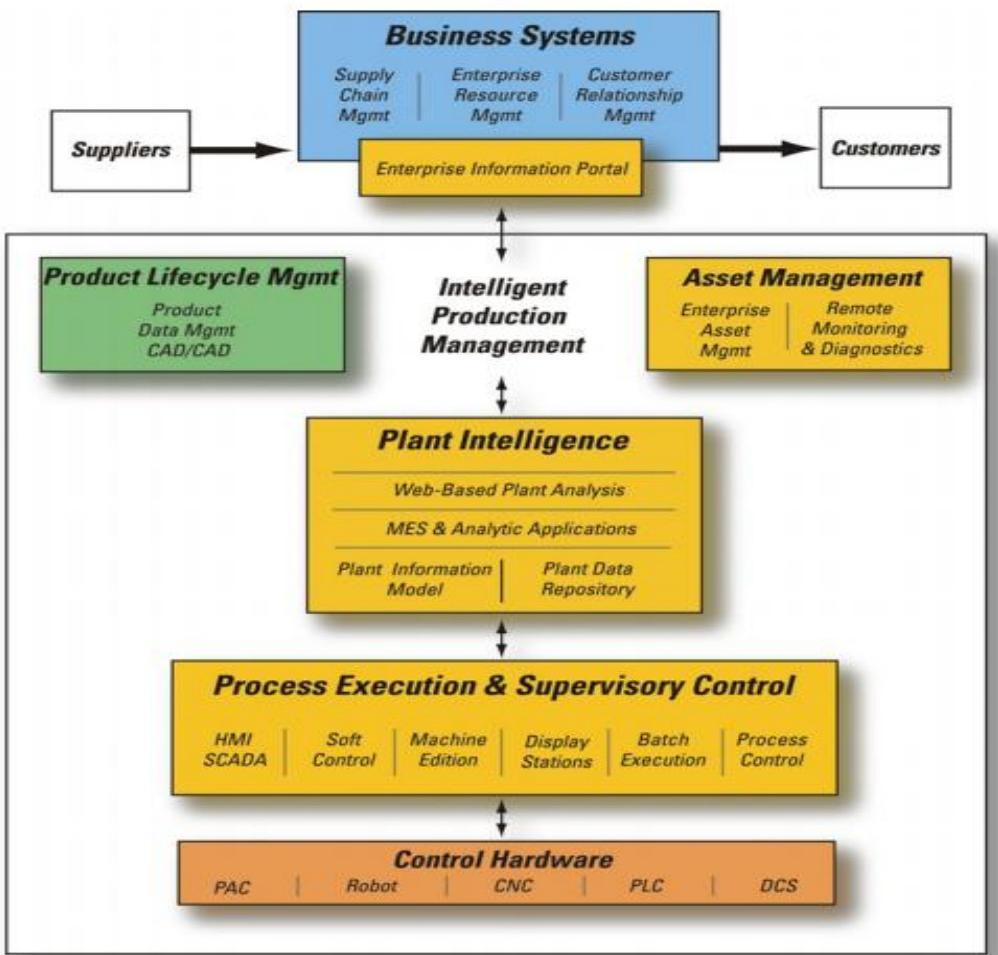


Fig 5.1: A management view of where the SCADA system sits in any business that can use it [30].

The Cimplicity software exists in the process execution and supervisory control level. It can be connected to one of the upper levels although this is not a requirement.

## 5.1 CIMPICITY SOFTWARE

Cimplicity is a visualization and control package that uses a client-server model. It helps the user to visualize the operation and perform high level analytical applications such as optimization. This creates a situation where the process engineers have fast responding control for maximum profitability. An example of a SCADA overview can be seen in Figure 5.1.1 where the operator has access to necessary information. In addition to this, the strip at the bottom shows controls in the form of electronic “push buttons”.

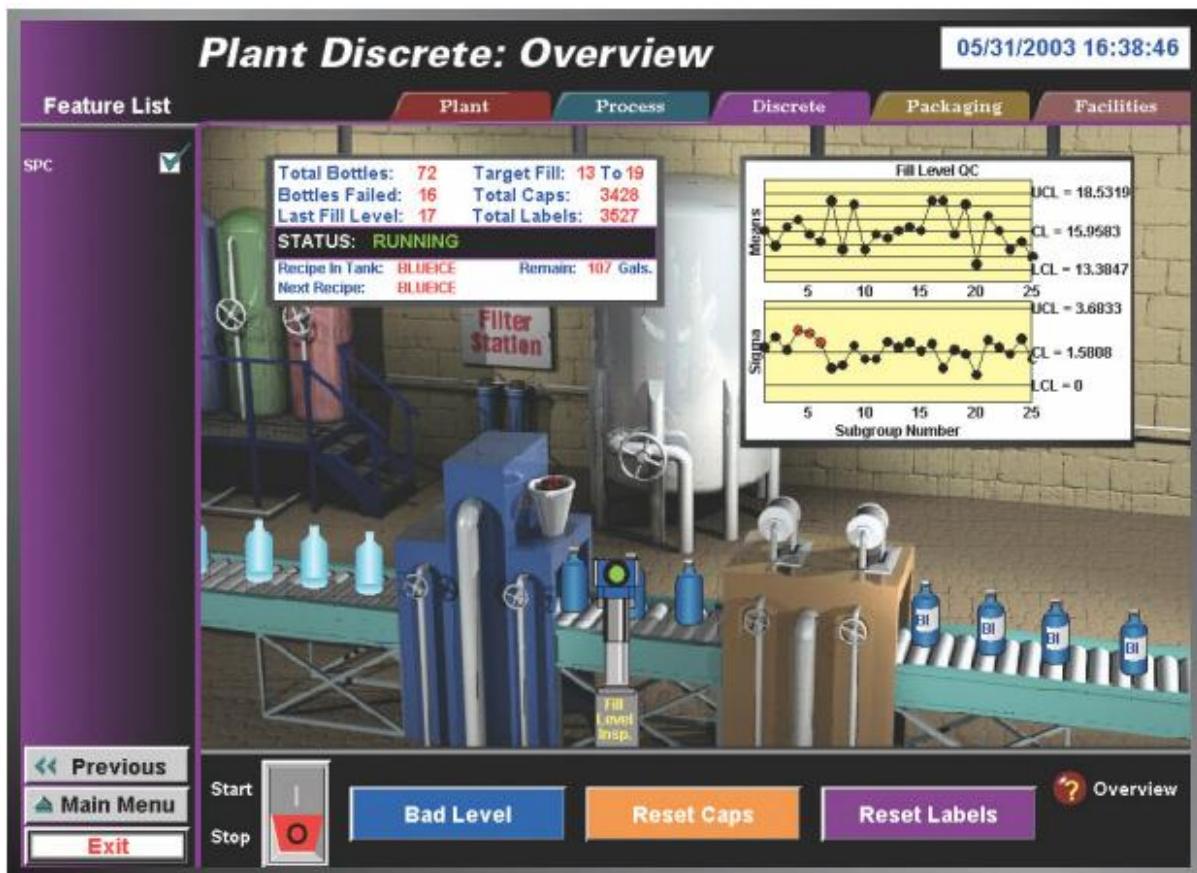


Fig 5.1.1: An example screen in a Cimplicity project [30].

The above screen has many features. These include title, tabbing, date/time, toolbar (left), user controls (bottom), indicator variables, a graphical display and a physical display of how the plant looks. The control items such as the start/stop and main menu are created in an editor to have a specific behaviour when a mouse is clicked on the icon. When using the tab section it may appear that only the mid-section changes; however a new screen must be designed and added for each tab. The indicators and display data are extracted from an external source. In this way the Cimplicity software acts as the client and is served the required information from the PLC (or other device).

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The work for each project is created in the editor known as Workbench. This provides thumbnails of all the screens created, classifies the screens into sections of the project and creates and manages objects and alarms. A screen shot of Workbench can be seen in Figure 5.1.2.

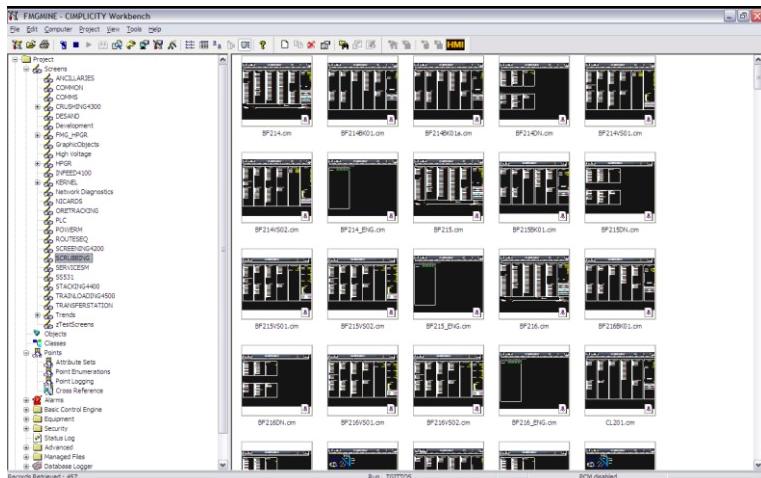


Fig 5.1.2: The workbench interface makes it easy to construct a project SCADA. The layout is such that navigation can is in a window on the left and screenshots of the actual pages are in the window on the right.

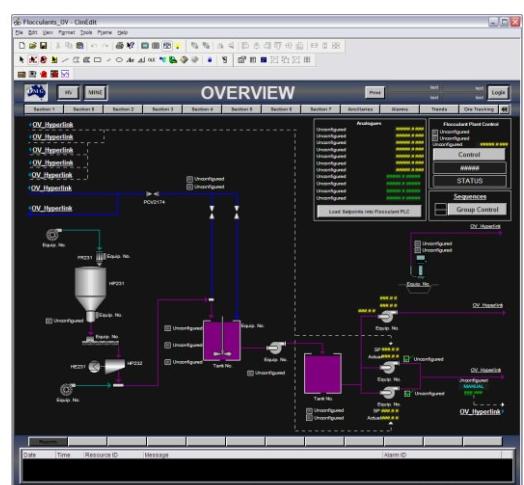
## 5.2 EXISTING SCREENS

The plant has already been in operation for some time and the software used for SCADA was Cimplicity 7.5. The latest current version is Cimplicity 8.2. This means that while working on this project it was important to have the correct software version since screens saved in a newer version cannot be used in a past version.

When a facility is upgraded such as FMG: Wet Front End is developed the company will opt, where they can, to keep the current software as it saves the cost of reprogramming the existing material. The previous Cimplicity screens were delivered to Motherwell for this purpose. The entire older section of screens could be altered rather than recreated and the “style” of the SCADA could be kept for the new sections of the plant. The types of screens created for this project are:

- Overviews – Display a large section of the plant with many objects and key indicator displays. These build up the foundation of the visual system and must be built to accurately reflect the plant physical layout. The control aspects are also shown using the white dotted line. Links to other overview screens help the user to navigate to a connected area without using the tabs.

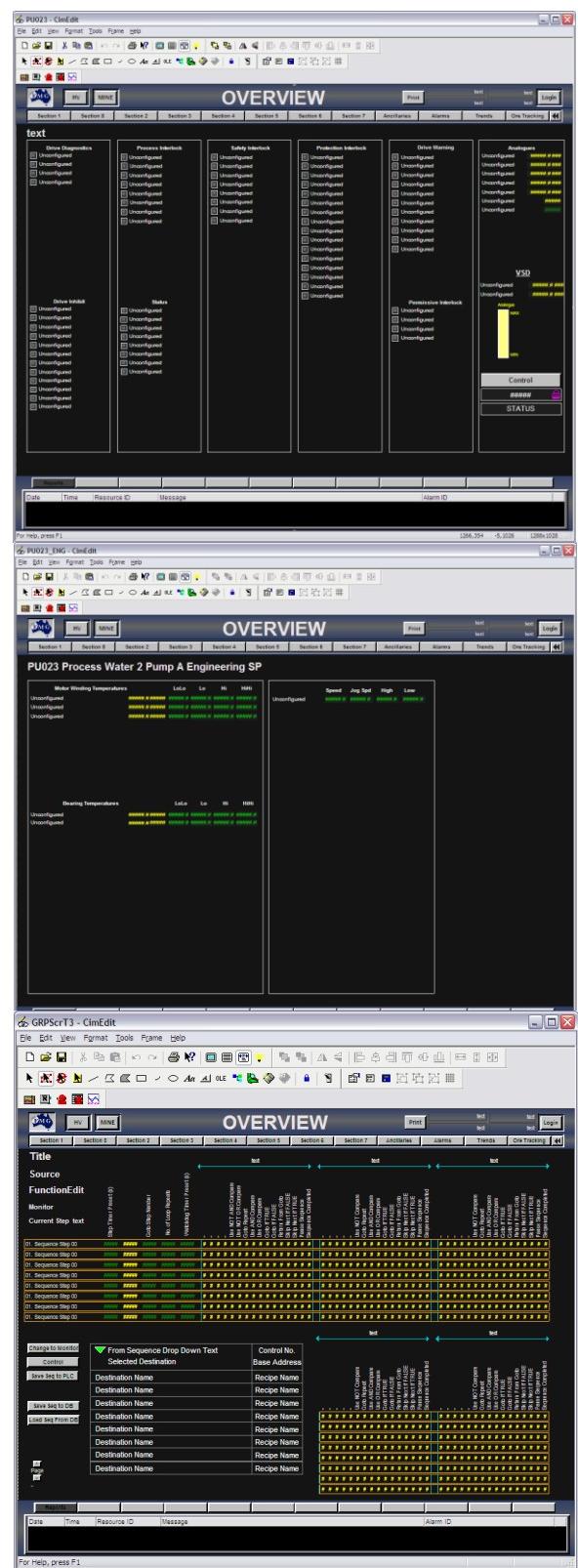
Fig 5.2.1: The flocculant overview screen.



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- Object Screens – Each object inside the overview is interactive and has its own screen that can be entered into upon the user clicking that object. This opens up into a two part section. The first is the interlock page that displays all the interlocks used by that particular object. Each interlock has a Boolean indicator that is green when interlock is not tripped and red otherwise. On this page the user can also see the VSD or other analogue values, diagnose a problem (if any), and change the mode of the object (manual remote, manual local or automatic). The second screen associated is the setpoint page where the user can change and/or monitor the setpoints for interlocks or controls. Fig 5.2.2: Both object screens for a VSD controlled pump in the desands section.

- DOL Screens – For a DOL drive the set point screen is smaller however another screen is included to show the status for the CEP7 and DNY42R.
- Valve Screens – A single screen that shows interlocks and diagnostics. Manual or automatic operation.
- Sequence Screens – These screens operated a sequence of events in automatic mode. They display which function are occurring at each section of a sequence in the form of a Boolean matrix. Fig 5.2.3: A sequence matrix screen.



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## 5.3 OBJECT ORIENTATED SCREENS

When creating a screen for an object it may be easier to create a generic screen that includes all possible points that a “class” of objects can have, for example the pump interlock screen. Then through Cimplicity software the points may be connected to a specific object of that class and the reference points will be filled in automatically. This way, each VSD pump in the SCADA can essentially be copy/pasted saving a vast amount of time. Having object orientation in the SCADA is a great advantage and opens up the ability to use spreadsheets to efficiently fill in the specifics to each item.

### 5.3.1 Excel and Cimplicity

Both Microsoft Excel and Cimplicity have the ability to generate classes and objects that have a specified amount of points (linked to the PLC). Instead of generating each object with a large amount of points and filling it in using the Cimplicity points view, which can be tedious, all the objects points can be exported to a CSV file. This is done by the following steps:

- 1) Open the command prompt
- 2) Get to the project directory and into the master file eg.  
C:\Proficy\Cimplicity\MyProject\Master
- 3) Use the command “clie export MyExportfile.csv”
- 4) This will export all the objects on the project unless a filter is used. A common filter is Sp- PU which will only select objects that contain the letters PU such as the pumps class (eg. PU266).
- 5) This objects file can now be opened in excel where it is relatively easy to fill out the required descriptions, alarms, constants, ect.
- 6) Once completed save the file and import it back into the master file directory using the command “clie import MyExportfile.csv”

The ability to export and import CSV files saves time and is a vital skill to have when working with Cimplicity.

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## 6 Network System

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Components such as hardware and software make up the bulk of a PCS. Data is still not free to move without a communications network that caters to the customized system. In this section the layout of the physical communications network will be discussed. The four main types of communications will be compared. The overall network should be designed and operate to complete the PCS solution for FMG: Wet Front End.

### 6.1 LAYOUT

The top level is where the process engineers directly interact with the PCS. These areas are referred to as Stations. Cloudbreak process facility has six control stations with six to ten PC computers in each. These Stations are connected to each other, the PLCs and the historian database servers in an Ethernet ring. The Ethernet network has multiple paths in which to travel to effectively bypass any errors in the system.

The inter-PLC communications is also covered by Ethernet however requires configuration of the EGD to be set up.

Many devices on the PLC network are gateways which communicate to instruments in another communications protocol. The DOLs use DeviceNet which is connected through the use of a DNY42R. The Versamax remote I/O modules use Profibus DP. The control valves and analogue sensors use Profibus PA.

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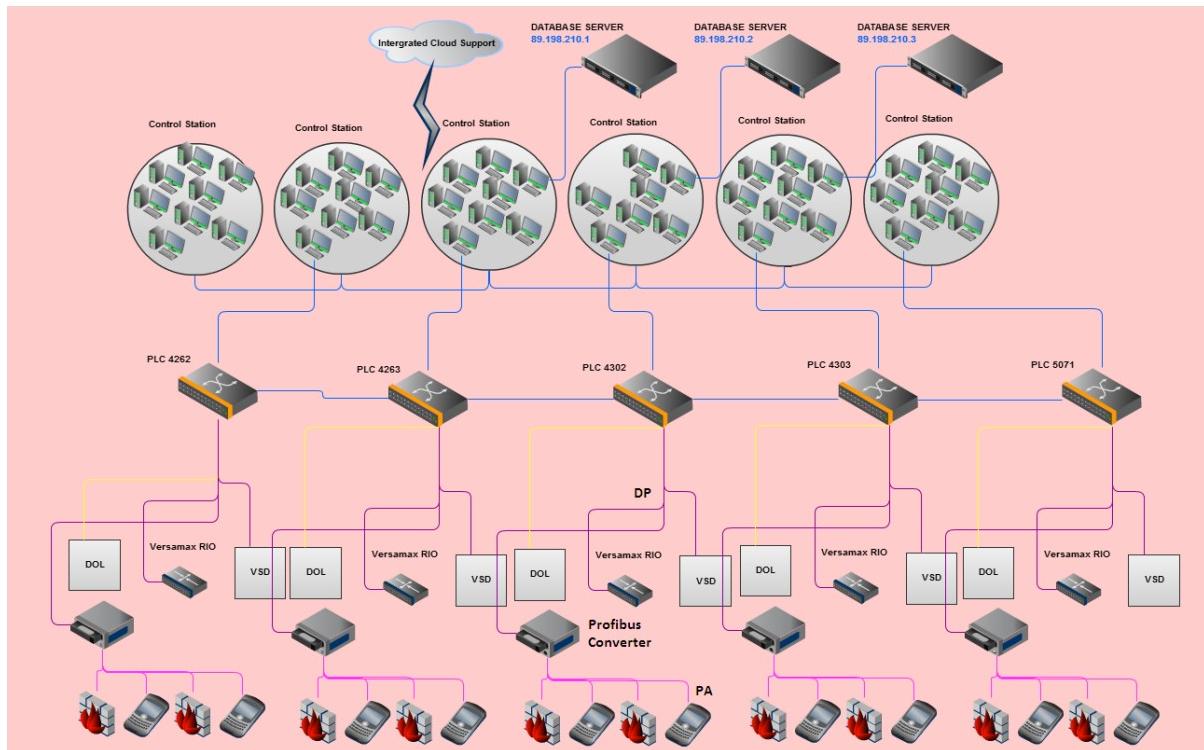


Fig 6.1.1: An overview of the network layout.

The Ethernet cables in Figure 6.1.1 are shown by the blue lines. Likewise, the yellow is DeviceNet, dark purple is Profibus DP and light purple is Profibus PA. It is important to recognise that this is not an accurate representation of the amount of devices attached to these PLCs but simply gives an indication of the network and communications type. Using more than one type of communications protocol was necessary to achieve the client's desired requirements.

## 7 Documentation

Each stage of a project this large has associated documents detailing the works at that stage. FMG: Wet Front End includes documents that are to be delivered to the client as proof of work done. Documents add structure and method to engineering work. They also clarify how the sections of work were divided up. For this project Motherwell constructed four key documents that are to be delivered to the client upon completion. These are the detailed design, FAT document, SAT document and the final product document.

### 7.1 DETAILED DESIGN SPECIFICATION

The first deliverable document is the detailed design. Similar to the way the project was divided into two sections, so was this document. In fact, all the major documents were divided into a desands document and a wet scrubbing document. The client hired AMC (consulting engineers) to test how close all the design specifications were followed from the documents FMG delivered [2] [5] [7].

The detailed design must be completed before any PLC or SCADA programming. It outlines all interlocks and controls to be programmed as well as modifications and upgrades and all other technical aspects of the project. A good understanding of the client's needs is required to complete such a document. This document is used as the basis for logic and all engineers actualizing programming are required to reference it.

### 7.2 FACTORY ACCEPTANCE TEST

The factory acceptance test document has been covered in the "PLC System" section. Its structure is such that all test components are listed and many tables are created so the testers can easily tick them off as they go. This document is required to be completed before the code can be transferred to site.

### 7.3 SITE ACCEPTANCE TEST

The site acceptance test document covers all connections to the onsite equipment. It tests the circuits, safety and functionality of the PCS. This document must also be 'checked off' while completing the test. It is structured into four parts. These are:

- Overview – Specifically informs all personal of the purpose of the test, where the test is performed and how (including specifying the software).

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- Entry Criteria – Clearly states all the actions performed before the test can take place. An example for this is a known fault that fails the test. The test can still be conducted provided that this fault is waived in writing by the client. Other entry requirements include that the test will satisfy its function and that no safety risk is violated. This section is overseen by a senior member of Motherwell Automation and must satisfy the company's codes.
- Display Tests – The main area of testing occurs in the field. Testing also occurs in the control room since remote operations are to be achieved as part of an effective PCS. Each hardware test usually has a corresponding alarm or visible change within the SCADA which can be used to test the display.
- Functional Tests – As written, each operation is performed one-by-one and the outcome is recorded. Any discrepancies must be solved before moving on.

A number of SAT documents must be drawn up for this project since there are many items to test and it is easier to test all items of the same class at the same time.

## 7.4 OPERATION MANUAL

Upon completion of the SAT the integrated system is ready for delivery. When this is the case a final document is produced that details the PCS and how to operate it. This is similar to a custom manual but also includes references to any documents that may help should there be any problems in the future. The operations manual highlights the correct operating procedure and normal operating ranges. This document is deliverable to the process engineers as well as senior management.

## 8 Outcomes

It is difficult to sum up just how important experience is to a young engineer. An engineering internship is a huge source of experience that rounds out developing engineering skills as well as adding in new industry relevant ones. Large engineering projects are an increasing proposition in the modern world. These require engineers of all specializations and background to complete. FMG: Wet Front End is a project that inundated the assigned undergraduate with engineering concepts and methodology.

Many facets of engineering knowledge were required to complete the FMG: Wet Front End project. The process control system was specifically contracted to Motherwell automation and this area of work coincided with the undergraduate's area of study. The software and hardware used in the project share similar features to those used in the Industrial Computer Systems engineering major. All of the necessary academic objectives were met during the course of this project.

## 8.1 ACHIEVEMENTS

### 8.1.1 Engineering Practice

Problems are certain to occur in a large project such as this one. Dealing with and managing problems is good engineering practice and should be done with a system or plan. In this project a few examples of the problems includes unexpected client requests to change the SCADA screens, overtime on allotted tasks such as the FAT and advanced control code required for the scrubber.

The changes were handled using the versatility of the team. Training was quickly supplied to those with lighter workloads and this was enforced with assigned tasks. Increasing the flexibility of the workforce kept the efficiency that FMG expected from a professional engineering firm.

While the FAT test went largely overtime, the experience provided in this test ensures a more systematic approach can be achieved on the next project. The true measure of this test is the success of the code when executed on site. It is preferable, however, to have an accurate code rather than save time and send partially complete code to site.

Writing advanced ladder logic comes with experience. The coding language is capable enough to handle the control mechanisms required. This task was originally delegated to the undergraduate but then given to a senior

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engineer to “clean up” and peer review. This feedback help to develop a learning environment.

### ***8.1.2 Materials, Components and Systems***

This area had the largest level of knowledge distributed. The project equipment section of this document can give an indication of just how many new components were discovered. While the university pushes a practical foundation, it is impossible to cover all components used in the industry. The systems used in this project were covered in detail. They can be applied to many industrial applications and using them was a great learning experience. The materials are simple in nature. Ore, water, slurry and thickener keep the objects used relatively generic. This means that the engineering materials used do not need advanced traits such as corrosive resistance.

### ***8.1.3 Engineering Project Management***

In addition to creating the three prime internship documents the undergraduate had access to a number of project management documents. These include design plans, cost analysis, tender documents and project scope documents. Anything not filled in by these documents was discovered through client liaison during the FAT. Effective project management was achieved in this project and an impression of this was received by the undergraduate.

### ***8.1.4 Engineering Operations***

This area involves working in an engineering team to complete engineering work. Engineering work is generally complex and requires significant planning, thought and accurate execution. Having a team gives the solution a higher chance of success. This is because engineers can take on a task from the project where their personal specialization lies. Watching and learning from senior engineers that do this helps an undergraduate develop good engineering practices.

### ***8.1.5 Self Management in an Engineering Workplace***

Professional skills are necessary to integrate successfully into a workplace. An adaptation has to be made when entering to what is arguably an alien environment. Ultimately dress and interpersonal behaviours have been set to higher standards.

### ***8.1.6 Investigating and Reporting***

This project has been thoroughly investigated. This should happen with every project undertaken as a good design can only stem from good

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understanding. The three reports and the corporate documents make up the reporting for this document. Together they can deliver very detailed knowledge about the works undertaken.

## 8.2 CONCLUSION

The final contribution an engineering student must make is an engineering thesis or internship. Motherwell Automation has taken on the undergraduate and presented the project FMG: Wet Front End as the subject matter. This project was worked on by a team of engineers from Motherwell and largely involved the majors of study, in particular, industrial computer systems engineering. Motherwell's friendly technical staff are ideal for introducing a young professional into the post-university world. This project successfully provided the undergraduate with a fantastic education on industry operations.

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## 9 Appendix

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### 9.1 STANDARDS AND CODES

All equipment and works shall comply with the current applicable Australian standards unless otherwise stated in contract documents.

Should no Australian standard be applicable, the works shall conform to the following standards unless otherwise stated in contract documents.

1. International Standards Association
2. ASME
3. AGMA
4. British Standards
5. CEMA

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## 9.2 VERSAMAX MODULES

<i>Discrete Input Modules</i>	
Input Module, 120VAC 8 Points	IC200MDL140
Input Module, 240VAC 8 Points	IC200MDL141
Input Module, 120VAC Isolated 8 Points	IC200MDL143
Input Module, 240VAC Isolated 4 Points	IC200MDL144
Input Module, 120VAC 16 Points	IC200MDL240
Input Module, 240VAC16 Points	IC200MDL241
Input Module, 120VAC Isolated 16 Points	IC200MDL243
Input Module, 240VAC Isolated 8 Points	IC200MDL244
Input Module, 125VDC Positive/Negative Logic Isolated 8 Points	IC200MDL631
Input Module, 125VDC Positive/Negative Logic Isolated 16 Points	IC200MDL632
Input Module, 48VDC Positive/Negative Logic Grouped 16 Points	IC200MDL635
Input Module, 48VDC Positive/Negative Logic Grouped 32 Points	IC200MDL636
Input Module, 24VDC Positive/Negative Logic 16 Points	IC200MDL640
Input Module, 5/12VDC Positive/Negative Logic Grouped 16 Points	IC200MDL643
Input Module, 5/12VDC Positive/Negative Logic Grouped 32 Point	IC200MDL644
Input Module, 24VDC Positive/Negative Logic (32 Points)	IC200MDL650
<i>Discrete Output Modules</i>	
Output Module, 120VAC 0.5 Amp, Isolated 8 Points	IC200MDL329
Output Module, 120VAC 0.5 Amp, Isolated 16 Points	IC200MDL330
Output Module, 120VAC 2.0 Amp, Isolated 8 Points	IC200MDL331
Output Module, 24VDC Positive Logic 2.0 Amps, w/ESCP 8 Points	IC200MDL730
Output Module, 12/24VDC Positive Logic 0.5 Amp, 16 Points	IC200MDL740
Output Module, 24VDC Positive Logic 0.5 Amp, w/ESCP 16 Points	IC200MDL741
Output Module, 24VDC Positive Logic 0.5 Amp, w/ESCP 32 Points	IC200MDL742
Output Module, 5/12/24V DC Negative Logic 0.5 Amp, 16 Points	IC200MDL743
Output Module, 5/12/24VDC Negative Logic 0.5 Amp, 32 Points	IC200MDL744
Output Module, 12/24VDC Positive Logic 0.5 Amp, 32 Points	IC200MDL750
Output Module, Relay 2.0 Ampt Isolated Form A 8 Points	IC200MDL930
Output Module, Relay 2.0 Amp, Isolated Form A 16 Points	IC200MDL940

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<i><b>Discrete Mixed I/O Modules</b></i>	
Mixed Module, 24VDC Positive Logic Input 20 Points / Output Relay 2.0 Amp 12 Points	IC200MDD840
Mixed Module, 24VDC Positive Logic Input 20 Points / Output 12 Point / (4) High Speed Counter, PWM, or Pulse Train Configurable Points	IC200MDD841
Mixed Module, Output 24VDC Pos. Logic 0.5A Grouped w/ESCP 16 Points / Input 24VDC Pos/Neg Logic Grouped 16 Points	IC200MDD842
Mixed Module, 24VDC Positive Logic Input Grouped 10 Points / Output Relay 2.0A per Point Grouped 6 Points	IC200MDD843
Mixed Module, Output 12/24VDC Pos. Logic 0.5A 16 Points / Input 24 VDC Pos/Neg Logic Grouped 16 Points	IC200MDD844
Mixed Module, Output Relay 2.0A Isolated 8 Points / Input 24VDC Pos/Neg Logic Grouped 16 Points	IC200MDD845
Mixed Module, Output Relay 2.0A per Pt Isolated 8 Points / Input 120VAC Grouped 8 Points	IC200MDD846
Mixed Module, Output Relay 2.0A per Pt Isolated 8 Points / Input 240VAC Grouped 8 Points	IC200MDD847
Mixed Module, Output 120VAC 0.5A per Pt Isolated 8 Points / Input 120VAC Grouped 8 Points	IC200MDD848
Mixed Module Output Relay 2.0A per Pt Isolated 8 Points / Input 120VAC Isolated 8 Points	IC200MDD849
Mixed Module, Output Relay 2.0A per Pt Isolated 8 Points / Input 240VAC Isolated 4 Points	IC200MDD850
Mixed Module, Output 12/24VDC Pos. Grouped 16 Pts / Input 5/12VDC Pos/Neg Grp16 Pts	IC200MDD851
<i><b>Analog Input Modules</b></i>	
Analog Input Module, 12 Bit Voltage/Current 4 Channels	IC200ALG230
Analog Input Module, 16 Bit Voltage/Current, 1500VAC Isolation, 8 Channels	IC200ALG240
Analog Input Module, 12 Bit Voltage/Current 8 Channels	IC200ALG260
Analog Input Module, 15 Bit Voltage Differential 8 Channels	IC200ALG261
Analog Input Module, 15 Bit Current Differential 8 Channels	IC200ALG262
Analog Input Module, 15 Bit Voltage 15 Channels	IC200ALG263
Analog Input Module, 15 Bit Current 15 Channels	IC200ALG264
Analog Input Module, 16 Bit RTD, 4 Channels	IC200ALG620
Analog Input Module, 16 Bit Thermocouple, 7 Channels	IC200ALG630
<i><b>Analog Output Modules</b></i>	
Analog Output Module, 12 Bit Current, 4 Channels	IC200ALG320
Analog Output Module, 12 Bit Voltage 0 to 10VDC 4 Channels	IC200ALG321
Analog Output Module, 12 Bit Voltage -10 to +10VDC 4 Channels	IC200ALG322
Analog Output Module, 13 Bit Voltage 8 Channels	IC200ALG325
Analog Output Module, 13 Bit Current 8 Channels	IC200ALG326
Analog Output Module, 13 Bit Voltage 12 Channels	IC200ALG327
Analog Output Module, 13 Bit Current 12 Channels	IC200ALG328
Analog Output Module, 16 Bit Voltage/Current, 1500VAC Isolation, 4 Channels	IC200ALG331
<i><b>Analog Mixed I/O Modules</b></i>	
Analog Mixed Module, 12 Bit Input Current 4 Channels and Output Current 2 Channels	IC200ALG430
Analog Mixed Module, 12 Bit 0 to 10VDC Input 4 Channels and Output 2 Channels	IC200ALG431
Analog Mixed Module, 12 Bit +/-10VDC Input 4 Channels and Output 2 Channels	IC200ALG432

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## 9.3 GLOSSARY

Word	Meaning
Transmitter	Used in the sense of a device that transmits data observed (sensor).
Optimised	To make something as effective as possible.
Interlock	Connection so that different inputs can affect the outputs.
Scope	The range of actions or requirements.
Algorithm	A step-by-step procedural method to solving a problem.
Analogue	Variable in reference to a measured value.
Solenoid	Electrical switch that is closed when power is received.
Logic	A system of reason that follows specific rules.
Server	A CPU set up to answer to a master CPU.
Database	A collection of data, usually in a server, arranged for ease and speed of search and retrieval.
Network	A system of communications that interconnect.

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